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Establishment of Upland and Bottomland Hardwood Agroforestry Plantations in Tennessee and Mississippi

David Michael Casey
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by David Michael Casey entitled "Establishment of Upland and Bottomland Hardwood Agroforestry Plantations in Tennessee and Mississippi." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Scott E. Schlarbaum, Major Professor

We have read this thesis and recommend its acceptance:

John T. Ammons, Fred L. Allen, Donald G. Hodges, William G. Minser III

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Vice Chancellor and
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Establishment of Upland and Bottomland Hardwood Agroforestry Plantations in Tennessee and Mississippi

A Thesis Presented for the Master of Science Degree

The University of Tennessee, Knoxville

David Michael Casey

August 2004

DEDICATION

This thesis is dedicated to the Lord of Heaven and Earth and His son, Jesus Christ the Messiah, who freely sacrificed Himself for everyone and is continually interceding for us. He has given me all that I have, including the opportunity and ability to complete this thesis.

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The goal of getting a degree in forestry at any level has long been a dream of mine. The privilege of earning a Master of Science degree in Forestry has proven to require more work and be more rewarding than I ever expected. I am indebted to many people for their help and encouragement during the course of my graduate career.

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daughter's life. In return, she selflessly gave her undying love and encouragement throughout the process. Hannah Grace, my daughter, has been an encouragement to Andee and I both through her sweet spirit this first year of her life.

ABSTRACT

The feasibility of alley cropping as a means of afforestation was studied across seven different study sites in western Tennessee and northern Mississippi. Seeds were collected from 11 oak (*Quercus spp*) species and black walnut (*Juglans nigra* L.) trees in the region and grown under nursery protocols that are designed to produce seedlings of optimal size in one year. Seedlings were lifted by genetic family after one year and initial seedling measurements were recorded. Four bottomland studies and three upland studies were then sorted into an incomplete block design with multiple species and families within each block.

Seedlings were planted by augers in an alley cropping design during the spring of 2003. Shortly after flushing, two of the bottomland sites were completely inundated by backwater flooding from Mississippi River tributaries for up to three weeks. The other two bottomland studies experienced soil saturation into June. First year growth, survival, and damage was recorded in the fall of 2003.

First year survival on bottomland sites was clearly affected by flood intensity and revealed a clear flood tolerance differentiation among species. Survival fell from 90 percent on one of the saturated sites to 35 percent on the most severely flooded site. Nuttall oak (*Quercus texana* Buckley), willow oak (*Quercus phellos* L.), swamp chestnut oak (*Quercus michauxii* Nutt.), and bur oak (*Quercus macrocarpa* Michx.) generally had the greatest survival across sites and appeared the least affected by flooding. The survival of all species increased with increasing root collar diameters and first order lateral roots.

Each bottomland site had an overall negative height growth (dieback) ranging from –14 to –62 cm. Water oak (*Quercus nigra* L.) and willow oak generally had the greatest amount of dieback. Height growth did not follow the flood tolerance of species as closely as survival, but was clearly affected by initial height in a negative relationship and root collar diameter and first order lateral roots in a positive relationship. Basal sprouting was a common response of water oak and willow oak to flooding and appeared to increase as flood severity increased to a certain point and then declined.

Upland survival was greater than 90 percent across study sites. Height growth means were good across sites except for the dieback on the northern red oak study site (*Quercus rubra* L.), which was probably due to late planting and drier than average roots at the time of planting.

Soybeans were planted between the tree rows on three sites. Soybean production was lower overall than the previous year, but still helped offset the cost of seedling establishment.

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CHAPTER I.

INTRODUCTION

Current reforestation *sensu lato* (Reed, 1983) efforts in the southern United States, particularly on bottomland sites, are greater than ever before (King and Keeland, 1999). Extensive portions of the southern United states, particularly the Lower Mississippi Alluvial Valley have been cleared for agricultural cropland over the past 200 years (Stanturf et al., 1998). However, generally low soybean prices and the marginal nature of some farmlands, in former bottomland hardwood forests, have now prompted landowners to consider reforesting the fields (King and Keeland, 1999). The growing need for protection of surface water quality and wildlife habitat restoration are important reasons for reforestation (King and Keeland, 1999). For fields that were formerly hardwood forests, reforestation strategies using artificial regeneration usually employ small, e.g. 12 – 24 inches tall, bare-root seedlings of uncertain seed sources require intensive competition control for establishment success. From an economic standpoint, the high initial investment of artificial regeneration followed by no immediate financial return usually precludes much, if any, subsequent site maintenance to encourage success (Stanturf et al., 2001).

Alley cropping is a form of agroforestry that may represent a viable alternative for landowners wishing to gain the benefits of reforestation, while maintaining a short-term income from row crops. Hodges *et al.* (1999) broadly defined alley cropping as "the planting of rows of trees and/or shrubs (single or multiple) at wide spacing, creating alleyways within which agricultural crops or horticultural crops are produced."

Agricultural cropping eventually ceases as tree crowns fill in the alleyways. A mature forest is one of the possible end products. Purposes of alley cropping may include the diversification of income, reduction of wind and water erosion, improvement of crop production, increased nutrient use, improvement of wildlife habitat, aesthetics, reforestation of cropland, and control of competition (Hodge et al., 1999).

Seedling quality, as measured by initial seedling measurements, is an important factor in survival and growth (Kormanik et al., 1995). Quality-improved seedlings from a local seed source are selected at the nursery for above average seedling measurements (Kormanik et al., 1993). The selected seedlings will have an increased probability of attaining a dominant or co-dominant crown position when outplanted (Kormanik et al., 2002; Schlarbaum et al., 1997).

This thesis research was conducted to determine the feasibility of alley cropping as a means of reforestation in western Tennessee and northern Mississippi using quality-improved seedlings. The following were the main objectives:

1) Analyze initial seedling measurements for differences among species and half-sibling genetic families;
2) Analyze first-year seedling survival, growth, and damage (species only) for differences among species and half-sibling genetic families;
3) Relate first-year seedling performance to selected site characteristics and initial seedling measurements, that may affect survival, growth, and damage of each species;
4) Report the initial costs of alley cropping in terms of establishment and reduced crop yield.

Chapter II.

LITERATURE REVIEW

Agroforestry

A form of agroforestry has been identified by pollen records as far back as 700 A.D in the mountains of Papua New Guinea and Irian Jaya (Brookfield and Padoch, 1994). The practice of intentionally growing trees alongside crops or pasture is one of the "oldest integrated traditional land use systems" (Rizvi et al., 1999). It has been suggested that the primary hypothesis of agroforestry is "benefits of growing trees with crops will occur only when the trees are able to acquire resources of water, light and nutrients that the crops would not otherwise acquire" which by default would increase the total productivity of the land (Cannell et al., 1996). However, Rizvi *et al.* (1999) indicate that by the end of the nineteenth century the main objective of applied agroforestry was the establishment of forest plantations for timber rather than an objective that combined timber and food crop. In the last 30 years, agroforestry research has focused on tropical and sub-tropical regions as a means of effectively handling the increased needs of a growing world population and reducing environmental degradation (Rizvi et al., 1999).

Temperate Agroforestry

The first attempt to introduce agroforestry in the United States was in the early 20^{th} century (Gold and Hanover, 1987). In 1914, J. Russell Smith, an economic geographer at Columbia University, sought to implement forms of the permanent tree-based agriculture that he witnessed in the Mediterranean region (Gold and Hanover, 1987). The United States government did not fully embrace Smith's ideas and for the next 50 years, agroforestry was considered only in times of environmental concern and abandoned during periods of affluence (Gold and Hanover, 1987). The United States Department of Agriculture recently expressed a focused interest in the concept of agroforestry by creating the National Agroforestry Center. As a result of this interest, agroforestry is an emerging land management alternative in the United States (Garrett and Buck, 1997).

Alley Cropping

The University of Missouri has been a leader in the research of temperate agroforestry with a focus on black walnut-based (*Juglans nigra* L.) alley cropping which dates to 1965 (Garrett et al., 1991). Black walnut was selected for the high value wood, nut production, and sparse foliage characteristics (Garrett et al., 1991). A common strategy has been to establish black walnut seedlings on a 40 by 10-foot spacing with row crops in between for the first 10 to 12 years; followed by cool season forages more suited to a reduced light regime (Garrett et al., 1991).

Garrett's approach to alley cropping has received much less study than tropical systems that typically utilize pruned leguminous trees to improve soil conditions for the crop by the presence of tree roots and using clippings as mulch (Schroth, 1999). Various views have touted alley cropping's ability to increase overall production production, but there are opposing philosophies. Sanchez (1995) regarded the above approach to tropical alley cropping as a general failure based upon the analysis of numerous plantings. He found that the competition effect of the trees on the crop outweighs any fertility benefit in all but the most luxuriant and sloping of environments. In response to Sanchez's paper, Vandermeer (1998) noted that datasets used by Sanchez were from alley cropping systems that were designed without the benefit of tree density and tree/crop competition research that would allow a more informed and quite possibly more productive design. It appears that alley cropping can be designed to maximize overall productivity as well as selectively increase one crop over another.

Temperate hardwood alley cropping research has also revealed a similar net negative effect on crop production primarily due to soil water competition (Jose et al., 2000; Miller and Pallardy, 2001; Ssekabembe et al., 1994). A reduction in crop yield, though, is generally deemed acceptable when the result is the production of high-value hardwood timber and/or nuts. Historically, alley cropping that focuses on timber/nut production and/or afforestation, more closely resembles a taungya system that is primarily practiced in the tropics. In a taungya system, the stand is harvested followed by burning of the slash and natural or artificial regeneration with the desired species. A food crop is then established in between the seedlings or sprouts (King, 1968). Management of the food crop prevents the trees from being overtaken by herbaceous vegetation during establishment, while the maximum productivity of the land is also realized. Shading eventually does not allow food production to continue; at which point the timber is allowed to monopolize the land for the remainder of the rotation age. Taungya growth rates are often greater than natural stands and offer the economic benefits of defraying early site maintenance costs and providing a land base for crop production (Chamshama et al., 1992; Nwonwu, 1987; Weaver, 1989). Alley cropping and taungya systems can share common goals, but a difference between the two is often the planting scheme. A taungya system incorporates the crop everywhere a tree is not, while alley cropping arranges the trees and crops in alleys.

Tree Growth and Spacing

A major consideration when designing an alley cropping system is the alley width. Widths must allow at least one passage of the widest farm implement, as well as providing sufficient sunlight for the crop until the trees begin to shade the crop rows. In most applications this minimum width for both equipment and sufficient light is approximately 30 to 40 feet. This width will also vary among regions due to different field layouts and concurrently different sized equipment.

The presence of an alley will naturally lead to a shorter clear bole and possibly greater stem taper, than that of a plantation with higher stocking rates with less sunlight reaching the bole (Smith et al., 1997). A spacing of approximately ten feet within the tree row will aid in reducing the negative effects of the wide alley on timber quality; however pruning will still be necessary for timber production (Balandier and Dupraz, 1999; Garrett et al., 1991). In France, Guitton (1996) reported that for a number of reasons including: genetic improvement of seedlings, poor markets for thinning products, and an increase in plantation cost, a trend of reducing plantation densities has resulted in agroforestry plantations. Analysis of 8-year-old hardwood agroforestry plantations across France have shown that tree form is not sacrificed by such low planting densities if pruned (Balandier and Dupraz, 1999). In addition, the general growth of trees in both height and diameter and the specific gravity, is greater in trees in an alley cropping system (B.E. and Garrett, 1993; Balandier and Dupraz, 1999; Cutter and Garrett, 1993).

Alleys may be designed to allow for crop production throughout the rotation age or narrow enough to require changes in alley composition over time, e.g. soybeans to tall fescue. If alleys are allowed to become too shaded for crop or forage production, natural regeneration of light-seeded species dispersed by wind and water may occur, provided a seed source or vector is within sufficient distance (Kennedy, 1992). This will add diversity to the stand and serve as a biological buffer against pathogen attacks that could otherwise decimate a stand of one or similar species (Schlarbaum et al., 1997).

Vegetation Control

In addition to plantation spacing, vegetation control is a management concern that can be alleviated by several different options. Garrett *et al.* (1991) have suggested that chemical control of vegetation is superior to most mechanical forms in maintaining tree vigor. An area around each tree or on both sides of a tree row is recommended to be vegetation free in most alley cropping applications (Balandier and Dupraz, 1999; Garrett et al., 1991). The use of herbicides has resulted in significantly larger seedlings than seedlings produced under cool-season legume treatments (Alley et al., 1999). Most studies have shown the advantages of competition control, but others, such as McLeod *et al.* (2000), indicate an indifference in the growth response of seedlings to competition control. Total vegetation suppression may not be the most advantageous for a number of reasons. Total vegetation control can encourage soil erosion (Pimentel et al., 1995), reduce soil organic matter and therefore degrade soil structure (Tisdale et al., 1993), reduce the value of the site for wildlife that use the vegetation for food or cover (Anonymous(b), ; Kennedy, 1992), and it can be expensive. The use of cool-season legumes as living mulches that compete minimally with the trees, provide nitrogen fixation, maintain soil structure and soil organic matter levels, prevent soil erosion and yet prevent unwanted vegetation may be the best method in some settings (Alley et al., 1999; Schroth et al., 2001; Van Sambeek et al., 1986). Living mulches comprised of grasses may be beneficial for several of the same reasons given for the legume living mulches. The use of living mulches has potential, but it should be noted that they can increase rodent populations, which can reduce seedling survival by predation (Kennedy, 1992; Ostfield et al., 1997).

Bottomland Hardwood Reforestation in the South

Historical documents suggest that the pre-European (1492) area of bottomland hardwood forests in the Lower Mississippi Alluvial Valley could have been as much as 24 million acres (Anonymous, 1992). Between the early 1800s and 1935, about one-half of this original forest was cleared for farmland (Stanturf et al., 1998). Another vast conversion of bottomland forests in this region to agricultural cropland occurred beginning in the late 1960's due to exceptional soybean prices (Sternnitzke, 1976). The soybean profit margins for production were so large that clearing edaphically and/or hydrologically marginal land was deemed profitable. In recent years, however, falling soybean prices combined with water quality and ecological issues, have prompted widespread restoration of bottomland forests (Stanturf et al., 1998). Federal agencies have established restoration projects on their own land as well as promoting restoration of private land through cost incentive programs such as the Conservation Reserve Program and the Wetland Reserve Program (Newling, 1990). In addition to the 5 million remaining acres (Conservancy, 1992), up to 500,000 acres of bottomland hardwood forests may be restored by 2005 (Stanturf et al., 2000). Despite current reforestation efforts, however, a recent survey indicates that the regional loss of forests from agriculture are still greater than restoration efforts (Hefner et al., 1994; King and Keeland, 1999).

Challenges of Establishing Bottomland Hardwoods

The most important consideration in establishing bottomland hardwoods is properly matching a tree species to the particular site (McLeod et al., 2000; Pezeshki and Anderson, 1997; Stanturf et al., 2000). Minor elevation differences in a floodplain are strongly correlated to variations in soil hydrology, drainage, moisture, texture, structure, and pH (Stanturf et al., 1998). Therefore, small topographic differences within a bottomland can greatly affect the species suitability for a particular area and has been responsible for many failed, or partially failed, reforestation attempts (Hook, 1969; Stanturf et al., 2001). At the most basic level, a species' flood tolerance has been noted by observing the species distribution across minor elevation and landform differences in existing bottomland hardwood stands (Hodges, 1997; Hodges and Switzer, 1979; Stanturf et al., 2001).

The critical factor for bottomland site selection is the hydroperiod, or duration of flooding, of a site (Stanturf et al., 2000). Along with hydroperiod, seasonal timing and oxygen content of the floodwater (stagnant vs. moving), and water depth are pivotal to species survival and vigor (Hook, 1984; Pezeshki and Anderson, 1997; Stanturf et al., 2000). The above factors determine the amount of oxygen that is available to a seedling subjected to flooding and/or soil saturation. Low redox potentials, as induced by varying periods of soil saturation, indicate a potential state of rhizosphere hypoxia in which there is insufficient oxygen to carry out aerobic respiration. Tree response during and after flooding is responsible for the differentiation of bottomland species into flood tolerant to non-flood tolerant species (Gardiner and Hodges, 1996). Flood tolerant species resume relatively normal stomatal and photosynthetic activity quickly after the onset of flood events, as opposed to a delayed or non-existent recovery in less flood tolerant species (DeLaune et al., 1998; Gardiner and Hodges, 1996; Gardiner et al., 1993; Gravatt and Kirby, 1998; McLeod et al., 1999; Pezeshki and Chambers, 1985; Pezeshki and Chambers, 1986; Pezeshki and Anderson, 1997; Pezeshki et al., 1999; Williams et al., 1993). Gravatt and Kirby (1998) also observed that less flood tolerant species experienced an increase in leaf starch concentration and a concurrent decrease in root starch concentrations during flood events indicating that the translocation of photosynthate is interrupted in less flood tolerant species. Carbohydrate reserves are of particular importance during the establishment of bottomland seedlings since they may allow for anaerobic respiration during periods of flooding (Crawford, 1976).

Soil Indicators of Seasonal Saturation

Knowledge of a site's typical soil saturation depth, frequency, and duration can be critical in planting the appropriate bottomland species on a particular site (Stanturf and Gardiner, 2000). Without personal knowledge of these site characteristics, accurate and precise hydrologic data of this nature is lacking. In the absence of these data, the soil profile itself may be replete with morphological features of reduction that can provide much of the soil moisture data necessary.

Vepraskas (2001) described the conditions necessary for the formation of reduction features. The process begins when an oxidized soil becomes saturated with water. When this occurs the movement of oxygen from the atmosphere into the soil is halted. The dissolved oxygen in the soil water is then reduced by respiring soil bacteria that oxidize organic compounds in the soil for energy. Soil features associated with the buildup of organic material begin to form at this point due to the fact that anaerobic decomposition is slower than aerobic decomposition. Without oxygen, the bacteria must use other electron acceptors to survive such as Fe and Mn. The reduction, movement and oxidation of these elements form the most widespread features of reduction, redoximorphic features. The time needed before Fe and Mn begin to reduce is directly dependent upon the interaction of soil temperature with the amount of organic carbon present in the soil and ranges from 6 to 160 days (Cogger and Kennedy, 1992). Soils with high organic matter content and high temperatures require the least amount of time to produce a reducing environment. Therefore, it is possible for a seasonally saturated horizon to show no signs of a reducing environment if a horizon is saturated during a period of the year that the temperature is too low for sufficient bacteria metabolism to deplete the oxygen (Cogger and Kennedy, 1992; Couto et al., 1985; Franzmeier et al., 1983). The level of seasonally-high saturation has generally been associated with the presence of redoximorphic features based upon various studies (Franzmeier et al., 1983; He et al., 2003; Jacobs et al., 2002; Simonson and Boersma, 1972; Vepraskas, 1992). West et al. (1998) found that horizons with redox concentrations, depletions and low-chroma matrix were saturated for 20, 40 and 50 percent, respectively, of a 805-day monitoring period.

An interesting difference has been observed between soils of different drainage classes and their relation to redoximorphic features (Genthner et al., 1998; Zobeck and Ritchie, 1984). The seasonal high water table is more shallow than Fe depletions in well drained and moderately well drained soils, whereas the seasonally high water table is deeper than Fe depletions in somewhat poorly drained, poorly drained and very poorly drained soils. The relationship between Fe depletions and the seasonally high water table are stronger than the relationship between Fe concentrations and the seasonally high water table (Genthner et al., 1998).

Veneman et al. (1998) offers an extensive literature review of studies on soil moisture and redoximorphic features since 1950. He describes the generally consistent relationship between redoximorphic features and soil saturation, but cautions the accuracy of using these features alone in some circumstances. One challenge in recognizing redoximorphic features occurs mainly in floodplains where the parent material may contain very small amounts of Fe and appear to have a low chroma (Lindbo, 1997). Lindbo noted the phenomena where soils that are flooded frequently or even for long durations may have no signs of reduction due to the fact that the floodwaters are sufficiently aerated. These studies indicate that comparing redoximorphic features across soil types will not always produce accurate comparisons of saturation depth, frequency or duration, but using these features to compare relatively homogeneous soils may produce more accurate results.

Flood Tolerance of Selected Bottomland Oak Species

For purposes of this study, the flood tolerances of Nuttall oak (*Quercus texana* Buckley), willow oak (*Quercus phellos* L.), water oak (*Quercus nigra* L.), swamp chestnut oak (*Quercus michauxii* Nutt.), Shumard oak (*Quercus shumardii* Buckl. var. *shumardii*), cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) and bur oak (*Quercus macrocarpa* Michx.) are important. The following studies combine to address all of these species.

These bottomland oak species represent a spectrum of flood tolerances. Hodges and Switzer (1979) identified species occurrence in relation to stream valley landforms. The landform associations observed by these authors are products of the hydroperiod, drainage and floodwater depth as related to the landform and position relative to the stream. With respect to major stream valleys, Nuttall oak is located on the flats of the active floodplain as well as the flats of the terrace. Water and willow oak are present on the ridges of the active floodplain and the flats of the terrace. Swamp chestnut, Shumard and cherrybark are located on the ridges of the terrace.

Kennedy (1990) classified common bottomland species according to their tolerance of both flood duration and seasonal timing of flood events. Nuttall oak had the widest range of tolerance, as it was tolerant of continuous flooding for January through May as well as January through March or May with only periodic flooding. Water and willow oak were both labeled as being tolerant of periodic flooding from January through May. Shumard, swamp chestnut and cherrybark were identified as tolerant of January through March periodic flooding.

The Army Corps of Engineers (Theriot, 1993) produced a flood tolerance rating for some tree species native to southeastern States. Species tolerances are ranked as: cherrybark oak, swamp chestnut oak and Shumard oak – weakly tolerant and Nuttall oak and willow oak – moderately tolerant. Weakly tolerant is defined as "those species capable of living from seedling through maturity in soils that are temporarily waterlogged for durations of 1-4 weeks, usually accounting for 10 percent of the growing season (Theriot, 1993)." Moderately tolerant is defined as "those species capable of living from seedling to maturity in soils that are waterlogged about 50 percent of the time. Waterlogging typically occurs in portions of the winter, spring, and early summer (Theriot, 1993)." All of the species above (except Nuttall oak) are classified as facultative wetland species that usually occur in wetlands, but occasionally are found in non-wetlands. Nuttall oak is classified as an obligate wetland species that almost always occurs in wetlands under natural conditions.

Steed et al. (2002) related the location of bottomland species within a stream valley by a more quantifiable method. The depth to gleying, a soil condition resulting from prolonged soil saturation, in the soil of the Hatchie National Wildlife Refuge was measured, and the various species present at each location was observed. Most of the selected species present exhibited a relatively weak relation to gleying depth. Willow oak was present where gleying was at the soil surface to 50 cm in depth. Water, swamp chestnut and cherrybark oaks were observed in soil with gleying from 20 to 80 cm below the surface. Shumard oak was only observed where the depth to gleying was 80 cm.

Silvics of Planted Bottomland Species

Cherrybark Oak

The form, stature and wood quality of cherrybark oak is superior to southern red oak (*Quercus falcata* Michx. var. falcata) making it an excellent timber species. Cherrybark oak is generally found on the well-drained bottomlands of the southeastern Coastal Plain and the Mississippi Alluvial Plain (Krinard, 1990).

One of the earliest studies on site index, i.e. the height at 50 years on a given site, of cherrybark indicated that surface drainage was the key factor in determining site index (Hebb, 1962). Broadfoot (1969) performed several site index studies that contributed to the combined effort of Baker and Broadfoot in 1979. This 1979 method created a more comprehensive site index predictive model based on numerous soil/site factors within the categories of soil physical condition, moisture availability during the growing season, nutrient availability and aeration. Their study reported the predicted site index for cherrybark oak, would be within 5 feet of the measured site index 95 percent of the time with a correct evaluation of all site factors. Subsequent studies have substantiated their analysis (Aust and Hodges, 1988; Belli et al., 1998). Studies have also shown that use of published soil surveys provide sufficient data to accurately determine site index using the

Baker and Broadfoot method (Broadfoot, 1969; Groninger et al., 1999; Groninger et al., 2000). The most important soil factors for cherrybark oak in Baker and Broadfoot's method are depth to mottling, depth of A-horizon and soil texture. The highest point values associated with these variables are associated with well-drained soils and produce a site index of 125. This method allows the calculation of a site index for a species that is not currently on site. Soil changes associated with long-term cultivation can also be accounted for using this site index method.

Cherrybark oak stomatal and photosynthetic activity is greatly reduced during continuous flooding conditions and lacks any significant morphological responses (substanitial adventitious roots, hypertrophied lenticels, etc.) that are correlated with a recovery of lost physiological function or at least an increase in survival (DeLaune et al., 1998; Gardiner and Krauss, 2001; Hosner and Boyce, 1962; Pezeshki and Chambers, 1985; Pezeshki and Anderson, 1997; Pezeshki et al., 1999; Williams et al., 1993). Similar to the other studies, McLeod et al. (2000) noted a positive correlation between planting elevation and cherrybark survival in a reforestation experiment. Seedling mortality in cherrybark oak is associated with flooding during periods of major vegetative growth, which suggests that there is not sufficient reserves to support the new vegetative sinks in the absence of photosynthate (Angelov et al., 1996). Unlike most other bottomland oak species, older cherrybark trees do not increase in diameter in response to limited flooding and cannot survive continuous flooding for a year or more (Hodges and Switzer, 1979).

Shumard Oak

Shumard oak is a large red oak with good form and excellent wood quality. Shumard oak is found in the Atlantic coastal plain from North Carolina to northern Florida and west to Texas; it is also found above the Lower Mississippi Alluvial Valley. The species grows best on well-drained alluvium and is noted for an ability to tolerate high soil pH levels (Edwards, 1990).

The most important factors related to site index for Shumard oak in Baker and Broadfoot's 1979 method are depth to mottling, soil color (in rooting zone) and depth of A-horizon. The values assigned are like cherrybark oak in that the highest scores are related to good soil drainage and produce a site index of 120. Shumard oak is rarely located on active floodplains (Edwards, 1990). Shumard oak has been shown to have no positive physiological or morphological responses to flooding and subsequently experiences high mortality (Hosner and Boyce, 1962).

Swamp Chestnut Oak

Swamp chestnut oak is a medium sized tree with good form and quality wood properties. It is found in the Atlantic Costal Plain from New Jersey to Texas and up the Lower Mississippi Alluvial Valley. The species grows best on well-drained alluvium soils (Hardin et al., 2001).

The most important factors related to site index for swamp chestnut oak in Baker and Broadfoot's method (1979) were soil depth, presence of a pan, depth of A-horizon and soil color (in the rooting zone). The values assigned to each of these favors a well-drained site and can produce a site index of 110. In a greenhouse study, Hook (1969) found that greater swamp chestnut oak growth during the first year was directly correlated to better drainage across all soil types. The second year, however, the drainage correlation was not significant, but the seedling in a silt loam had the greatest growth. The photosynthetic and stomatal function of swamp chestnut oak are lowered significantly the first day of flooding and show no signs of regaining lost function (McLeod et al., 1999). Seedling mortality in swamp chestnut oak is associated with flooding during periods of major vegetative growth, which suggests that there are not sufficient reserves to support new sinks (Angelov et al., 1996).

Bur Oak

Bur oak is a medium to large size tree that produces commercially valuable wood. It ranges across the central states, into the Great Plain States, north into Canada and south into Texas, central Tennessee and northern portions of the Lower Mississippi Alluvial Valley. Bur oak is found in many different environments throughout the range. The species is associated with gallery forests and xeric ridges in the forest-prarie transition zone and bottomlands near the Mississippi River (Abrams, 1986). Three varieties have been identified and are found in differing geographic regions (Johnson, 1990; Termenstein, 1988). Despite structural differences across the varieties, bur oaks across the range appear to exhibit a mixture of strong drought tolerance and moderate flood tolerance (Cogliastrio et al., 1997; Hamerlynck and Knapp, 1996; Loucks and Keen, 1973). Tang and Kozlowski (1982) reported that flooded bur oak experienced a significant reduction in stomatal function and subsequent reduction in growth especially in the roots. Morphological responses to flooding, however, included the formation of hypertrophied lenticels and a few adventitious roots during the 30-day flooding experiment.

Water Oak

Water oak is a medium-sized, fast growing tree that is common on cutover lands. It is found in moist bottomlands as well as uplands mainly along the coastal plain from New Jersey to Texas (Hardin et al., 2001).

The most important factors in Baker and Broadfoot's 1979 site index method for water oak survival and growth are depth to mottling and soil color (in the root zone). The values assigned to these factors increase as the drainage improves and can produce a site index up to 115 at fifty years.

Photosynthetic and stomatal function are not affected by flooding for the first 20 days of continuous flooding (McLeod et al., 1999). In a 32 day flooding trial, water oak photosynthetic rates dropped significantly, but the stomatal conductance values dropped only slightly and resembled a more flood tolerant species (Gravatt and Kirby, 1998). Water oak seedlings grown in a hypoxic solution for 35 days experienced a significant reduction in stomatal function and produced only one-third the growth of seedlings grown in a normoxic solution (Gardiner et al., 1993). Water oak has been observed to have good survival across bottomland soil types, however, shoot dieback can be severe on hydric soils (Williams et al., 1993).

The severe dieback is particularly noticed in the artificial regeneration of water oak via bare-root seedlings. Adams (1982) noted three distinct patterns of dieback from a normal leaf flush followed by dieback and sprouting lower on the stem to an apparently dead seedling that flushes in mid-summer from the root collar or lower. Flushing that occurs along the stem after dieback produced generally smaller and less vigorous leaves than flushes that originate at or below the root collar. The author puts forth two suggestions to minimize water oak dieback: (1) avoid seedlings that are greater than 36 inches to maintain an acceptable root/shoot ratio; and (2) lift the seedlings during the cold winter months to minimize the possibility that the persistent leaves will begin to photosynthesize prior to lifting and therefore increase transplant shock. Toliver et al. (1980) studied the effects of various top and root pruning treatments applied to water and willow oak both in the nursery and after outplanting. They discovered that after five seasons outplanted there were no significant differences in survival or height growth for these species. In contrast, Adams (1984) found that by pruning the top of water oak to either half the stem height or to 2.5 cm above the soil produced a much more vigorous seedling that is expected to overtop the unpruned seedlings or at least exhibit greater survival. Adams (1986) also set out to determine if various environmental factors at the time of nursery lifting affected the field performance of water oak. Generally poor vigor and a widespread lack of terminal bud growth was observed, but noted that the only significant environmental correlation was the photoperiod at the time of lifting. Water oak lifted when the photoperiod reached 12 hours resulted in more severe dieback, poorer growth and lower survival.

Willow Oak

Willow oak is a medium to large size tree that is an important source of lumber and pulp and is known for heavy annual acorn production, which benefits wildlife. It is found in moist bottomlands as well as moist uplands along the coastal plain from New Jersey to Texas, except Florida and southeastern Georgia, and north into Kentucky and Missouri (Hardin et al., 2001).

Willow oak and water oak are treated identically in Baker and Broadfoot's site index rating (1979), with depth to mottling and soil color in the rooting zone being the most important factors, indicating the importance of better drainage.

Mature willow oaks on certain sites in Louisiana have recently experienced severe dieback and death (Leininger, 1998). The declining willow oaks appear to be on a soil with a shallow A-horizon that is underlain by a deep layer of silty-sand, which is prone to droughty conditions. It is thought that the physiological stress of floods increases the likelihood of subsequent attacks by drought and disease (Leininger, 1998). Flooded willow oak seedlings were observed to have one-third the growth and transpiration of non-flooded seedlings (Gardiner et al., 1993). First-year results of 1-0 outplanted willow oaks revealed a positive correlation between survival and the relative planting elevation, which is often correlated to concurrent changes in soil properties (McLeod et al., 2000). Hosner and Boyce (1962) showed that willow oak has a slight production of adventitious roots and no shoot mortality in response to flooding.

Nuttall Oak

Nuttall oak is considered a medium-size tree occurring in the southcentral states, primarily in the Lower Mississippi Alluvial Valley. It is noted for rapid growth on poorly-drained, heavy clay bottomlands (Hardin et al., 2001).

Baker and Broadfoot (1979) deemed a deep soil and the absence of a pan as the most important factors to good Nuttall growth which can result in a site index up to 120. McLeod et al. (1999) reported a delayed, rather than immediate, reduction in photosynthetic and stomatal function in flooded Nuttall oak. In a 70-day flood experiment, Nuttall oak formed hypertrophied lenticels by day 28 and adventitious roots by the fifth week as well as continuing height growth throughout the experiment (Pezeshki and Anderson, 1997). First-year results of an outplanting of Nuttall oak and other oak species revealed that Nuttall had the highest survival and least amount of dieback across all soil types (Williams et al., 1993). Nuttall did, however, experience its greatest dieback on the drier soils in the study. Pezeshki et al. (1999) noted a reduction in biomass accumulation with flooded Nuttall. Survival of outplanted Nuttall oak has been reported to be unaffected by relative planting elevation in a bottomland (McLeod et al., 2000). Outplanted seedlings have survived two months of flooding during the growing season (Hook, 1984).

Genetics of Flood Tolerance

Genetic variation in flood tolerance has long been observed within tree species, but has not been well understood (Keeley, 1979). Turesson (1922; 1925) showed how natural selection could produce genetically different populations within the same species that are adapted to their respective environments. Keeley (1979) examined population differences in swamp tupelo (*Nyssa silvatica* Marsh.) with respect to flood tolerance. Progeny were selected from mother trees located in upland, floodplain and swamp locations. After growing each progeny across each landscape position, it was apparent that each had been naturally selected for optimum growth and survival in the mother tree's environment. It was also concluded that the progeny selected from the floodplain had characteristics that were the most plastic in order to deal with their dynamic moisture environment representing perhaps the "optimum compromise" instead of being selected for one extreme or the other. Phenotypic variation within provenances of European beech (*Fagus sylvatica* L.) have also been observed in response to increasing soil water content (Nielsen and Jorgensen, 2003).

Silvics of Planted Upland Species

Upland oak species face many of the same general exogenous disturbances as bottomland oaks, i.e. deer browse, disease, wind damage. However, upland oak species are often not subjected to frequent and unique disturbances such as the flooding of a bottomland stand. Therefore, the silvics presented below are less intensive than the bottomland species.

Southern Red Oak

Southern red oak (*Quercus falcata*) is a medium size tree that is one of the most common upland southern oaks (Hardin et al., 2001). The wood of southern red oak is strong and hard making it suitable for furniture and general construction. It is often found on the more xeric sites (Hardin et al., 2001). The range of southern red oak extends west out of the southeastern States into Texas and Oklahoma.

Black Oak

Black oak (*Quercus velutina* Lam.) is a medium size tree that is most often found on dry upland sites, but it can extend into well-drained bottoms (Hardin et al., 2001). Black oak lumber is valuable for furniture and flooring. Acorn production is substantial and thus important as food for wildlife. Black oak ranges over the eastern States and extends into the Great Plains.

Pin Oak

Pin oak (*Quercus palustris* Muenchh.) is a medium size tree that is found on both moist bottoms and upland sites (Hardin et al., 2001). The lumber potential of pin oak is low due the lack of self pruning, but the wood is hard and heavy. Pin oak is noted for excellent acorn production on mesic sites and thus an important source of mast for wildlife (Hardin et al., 2001). Pin oak extends from northeastern States to northcentral states and south into Tennessee and Arkansas.

White Oak

White oak (*Quercus alba* L.) is a large tree that is found on both xeric and mesic sites (Hardin et al., 2001). White oak produces the most important white oak lumber and is used for many uses including furniture and staves for barrels. The acorns of white oak are an important source of food for wildlife. White oak is located in the eastern States and into the Great Plains.

Black Walnut

Black walnut (*Juglans nigra* L.) is a medium size tree that is one of the most highly valued hardwoods in North America (Hardin et al., 2001). The valuable lumber is used for fine furniture and, with a decreasing supply, veneer. Squirrels consume the nuts when available. Black walnut is very sensitive to poor soil conditions and grows quickly on mesic sites (Hardin et al., 2001). Black walnut is found in most of the eastern States as well as the Great Plains.

Northern Red Oak

Northern red oak (*Quercus rubra* L.) is a medium to large size tree that is likely the most important tree of the genus (Hardin et al., 2001). Northern red oak is a very important red oak source for furniture and flooring. Northern red oak may be found on several different sites, but best growth is on fine-textured, moist soils with good surface drainage (Hardin et al., 2001). White oak is located in the eastern States and into the Great Plains.

Pecan

Pecan (*Carya illinoensis* (Wangenh.) K. Koch) is a large tree that is found on moist, well drained sites (Hardin et al., 2001). Pecan wood has many uses, such as furniture, but the primary value of the tree is nut production. Pecan is found in the Lower Mississippi Alluvial Valley and extends into Texas, Iowa and Indiana.

Hardwood Seedling Quality

Seedling quality affects the success of the future stand (Buckley, 2002; Kormanik et al., 2002). Nursery produced seedlings are often small in an effort to produce a uniform seedling size. This approach has resulted in small seedlings, i.e. 23 cm northern red oak seedlings, that do not satisfy landowner objectives of oak reforestation without extensive site preparation and often well-timed and repeated competition control that is expensive (Buckley, 2002; Hodges and Janzen, 1986; Schlarbaum et al., 1997; Stroempl, 1985). The performance of 1-0 northern red oak seedlings in northern states was compared to that of direct seeding acorns, but have a higher financial cost (Zaczek et al., 1996). Stroempl (1985) recognized the need for grading of nursery stock when working with 2-0 seedlings out of which only 40 percent were deemed acceptable in quality.

Kormanik studied sweetgum and oak seedlings to identify a morphological measure of a seedling's competitiveness (Kormanik, 1986; Kormanik and Ruehle, 1986; Kormanik et al., 1989; Kormanik et al., 1997a; Kormanik et al., 2002). He found that sweetgum's survival, dieback and height growth in the field were all directly related to the number of first order lateral roots (FOLRs) present at lifting. The seedlings with the greatest number of FOLRs consistently had more height growth, less dieback and greater survival than those with less FOLRs. Various edaphic conditions did not affect the number of FOLRs, thus indicating genetic control over this trait (Kormanik and Ruehle, 1986). Other studies have suggested that a combination of morphological traits should be considered as indicators of future competitiveness (Hodges and Janzen, 1986; Kaczmarek and Pope, 1992).

Kormanik et al. (1993) developed a nursery protocol that produced a high quality seedling and thus allowed for the full development of FOLRs, height, and root collar diameter. This greater development produces a stratification in seedling size and permits easier identification of quality phenotypes by nursery personnel at the time of lifting (Clark et al., 2000). The selected, high quality seedlings show an initial size advantage over average 1-0 nursery-grown seedlings (Kormanik and Ruehle, 1986; Kormanik et al., 1993). Individual seedlings that had a greater number of FOLRs in a given species were in a dominant or codominant crown position in the nursery and therefore were expected to be competitive when outplanted (Kormanik et al., 1997b). Based on these parameters, between 40 and 60 percent of lifted material in a given species may not be competitive when outplanted and should be culled at the nursery. Clark et al. (2000) observed a sharp decline in seedling quality after the best 18% of seedlings, although the best 36% were deemed plantable. This lead to the distinction of "good" and "premium" seedlings that were considered to be plantable.

Thompson and Schultz (1995) observed similar results to Kormanik with a positive correlation between the number of FOLRs and seedling height growth during the first year of outplanting, but a negative correlation between initial height and first year growth. In a seven year study, large seedlings with a high number of FOLRs competed effectively with volunteer vegetation on a clearcut, mesic site (Kormanik et al., 1997a). They suggested that control of the extremely fast growing stump sprouts and yellow poplar seedlings may be needed after age seven. Schlarbaum *et al.* (1997) indicated that conventional oak seedlings available from nurseries are almost assured of being overtopped quickly by competition. They also affirmed the need for grading of oak seedlings in order to ensure that seedlings have a credible ability to compete with surrounding vegetation. Even with large, quality-improved seedlings, often competition control will still be necessary to some degree for sufficient establishment of oaks on high quality sites (Kormanik et al., 2002).

Utilization of Oaks

Oaks harvested for timber or standing in a forest have long been held in high esteem (Hardin et al., 2001). Oaks provide more native timber than any other group of hardwoods on an annual basis (Hardin et al., 2001). Oak lumber is hard and strong and generally regarded as furniture grade.

Oaks have often been cited as providing extremely important resources to wildlife. Bottomland hardwood forests that contain a large oak/hard mast component, support two to five times the number of game animals than do upland pine sites (Kennedy, 1992). Mixed bottomland hardwood stands have twice the avian conservation value of intensively managed cottonwood plantations (Twedt et al., 1999). Similarly, the species and proportion of oaks in a stand are positively correlated with providing forage to waterfowl (Allen, 1987).

Twedt and Wilson (2002) recommended that when using seedlings in afforestation projects to include several species and leave non-planted areas throughout the site. This will allow for increased structural and floristic diversity, through natural invasion of mainly light-seeded species, which will provide habitat for a variety of wildlife species. Afforestation using fast growing species alone or in conjunction with oaks is superior to afforestation that utilizes just oaks when managing for forest-breeding, neotropical migratory birds (Twedt and Portwood, 1997).

Kennedy (1992) notes that intense weed control can reduce the short-term wildlife value of a plantation for species that use weeds for food and cover. When alley cropping, living groundcovers, planting two or three trees between crop rows (wider tree rows), avoiding straight-line designs, and leaving some of the crop at harvest will greatly benefit wildlife (Anonymous(a)).

CHAPTER III.

MATERIALS and METHODS

Seed Collection and Handling

Currently there are no producing hardwood seed orchards in western Tennessee or northern Mississippi. Therefore, seed was collected from local seed sources (Post et al., 2003). Open-pollinated, half-sibling families (families) were collected from individual mother trees in the Lower Mississippi Alluvial Plain and East Gulf Coastal Plain of Tennessee and Mississippi in the fall of 2001 (Table 1). Each seedlot was labeled with a family name, date of collection, and location of mother tree.

The acorns were subjected to a flotation test for viability (Olson, 1974). The floating acorns were discarded, and the sinking acorns were kept for planting. The retained acorns were placed again in plastic bags and stored in refrigeration. The black walnuts were dehusked and stored under refrigeration. Family identity was maintained throughout seed collection and handling procedures. Seed was then sorted into an incomplete block within complete block experimental design with two replications for nursery sowing.

Nursery Sowing and Management

The acorns and black walnuts were hand sown in December of 2001 at the Georgia Forestry Commission Flint River Nursery near Montezuma, Georgia. Each block was sown with 180 acorns or black walnuts of the same family. Families were

Table 1 - Number of families collected for each species.

Species	# Families
Water oak	54
Cherrybark oak	28
Nuttall oak	13
Willow oak	54
Shumard oak	5
Swamp chestnut oak	4
Bur oak	2
Black oak	7
Southern red oak	8
Pin oak	6
Black walnut	9
Northern red oak	21
White oak	12
Total	223

replicated with the exception of southern red oak, Nuttall oak and Shumard oak families. A three-foot gap was placed between seedlots to retain genetic identity during lifting operations. The resulting seedlings were grown according to protocols developed by the USDA Forest Service's Institute for Tree Root Biology (Kormanik et al., 1993).

Seedling Lifting

Lifting occurred in early February of 2003 with a Fobra™ machine lifter that was set to undercut at a depth of 30 cm. For each seedlot, 90 seedlings were randomly selected for a sample. Ninety (90) seedlings were determined to be a sufficient sample size that would provide accurate estimates of family means (Maxedon, 2000). Tree Improvement personnel determined a visual cull standard for the remaining seedlings in each seedlot, and the larger seedlings were retained ("leftovers"). The seedlings were then transported to east Tennessee and placed in cold storage at the Tennessee Division of Forestry East Tennessee State Nursery until growth characteristics were evaluated.

Measurements

A uniquely numbered tag was attached to each seedling. Family identity and nursery information were recorded for each seedling. Stem height and root collar diameter (RCD) at the soil line were measured. First order lateral roots greater than 1 mm in diameter were counted on the seedlings, except for the black walnut seedlings since most of the root resources are concentrated in the tap root. Measurements were recorded for each seedling. Lateral roots were pruned to six inches to aid in planting.

Experimental Sites

Wallace Johnston Tree Farm

Two stream valley sites (30 acres) were planted on the Wallace Johnston Tree Farm (WJ – S and WJ – N) near Hickory Flat, MS. The WJ – S site is 25 acres and the WJ – N site is 5 acres. The sites are located in a minor bottom (Hodges, 1997) along Mill Creek within the East Gulf Coastal Plain (USGS, 2003). The flood regime has been altered due to the construction of an earthen dam (circa 1950) immediately upstream of the sites. The sites are subject to ponding water from precipitation and overland flow from adjacent uplands. Soils have been characterized as silt loams of the Collins, Falaya, and Henry series with redox depletions at or near the surface over much of the site. Soil pH ranges from 5.0 to 7.0.

FWS Lower Hatchie NWR Champion Lake

The 10 acre U.S. Fish and Wildlife Service Lower Hatchie National Wildlife Refuge stream valley study site (LH – CL) is located next to Champion Lake in the Refuge. The study is in a major bottom (Hodges, 1997) located near the confluence of the Hatchie and Mississippi Rivers. The Hatchie River is the only unchannelized Mississippi River tributary in Tennessee (Steed et al., 2002), which makes this study site prone to backwater flooding. The site is within the Mississippi Alluvial Plain physiographic region of Tennessee (USGS, 2003). Topographic relief across the site is approximately eight feet. Soils have been characterized as Askew silt loam and Amagon silty clay loam with redox depletions from the soil surface to twenty centimeters. Soil pH ranges from 5.0 to 8.0. Eastern cottonwood (*Populus deltoides* Batr. Ex Marsh.) has been observed as a common volunteer tree species on this site.

TWRA Moss Island WMA

The Tennessee Wildlife Resources Agency's Moss Island Wildlife Management Area study site (MI) is aproximately 10 acres and is in the floodplain of a major bottom (Hodges, 1997), located near the confluence of the Obion and Mississippi Rivers. This site is also situated in Mississippi Alluvial Plain (USGS, 2003). The Obion River has been channelized (Steed et al., 2002) upstream of the study location and is prone to backwater flooding. Topographic relief across the site is approximately six feet. Soils have been characterized as Tunica clay with redox depletions from the soil surface to three centimeters. Soil pH ranges from 6.5 to 8.0. Black willow (*Salix nigra* Marsh.) has been observed as a common volunteer tree species on the wettest portions of the site.

Strawberry Plains Audubon Center

The Strawberry Plain Audubon Center study (AC) consists of 10 acres and is located near Holly Springs, MS. The site is within the East Gulf Coastal Plain (Anonymous, 2003) on an upland landform (Hodges, 1997). Slope is less than five percent, and the soils are classified as Lexington and Loring silt loams with redox depletions between five and thirty two centimeters. Soil pH ranges from 4.5 to 5.5. Kudzu (*Pueraria lobata)* has overtaken land on two sides of the site, but is being controlled from invading the site. There is extensive volunteer sweetgum (*Liquidambar styraciflua* L.) on uncultivated land near the site.

FWS Lower Hatchie NWR – Upland Site

The 5 acre US Fish and Wildlife Service Lower Hatchie National Wildlife Refuge upland study site (LH – UP) is located within 1 mile of the site. Slope is less than two percent over most of the site, and the soils are classified as a Memphis silt loam with no redox depletions above fifty centimeters. Soil pH ranges from 6.5 to 7.0.

Pat Estes Tree Farm

The Pat Estes Tree Farm study site (PE) is a 1 acre plot located near Big Sandy, Tennessee. The site is at the eastern extent of the East Gulf Coastal Plain physiographic region (Anonymous, 2003) on a terrace landform (Hodges, 1997). Slope is less than three percent, and the soils are classified as silt and silt loam with redox depletions occurring from six to greater than forty centimeters. Soil pH is 5.5.

All study sites were planted in soybeans (*Glycine max* (L.) Merr.) during the 2002 growing season with the exception of the Pat Estes Tree Farm, which is an old field site.

Experimental Design and Establishment

Seedlings that were visually greater than the family mean were sorted into an incomplete block experimental design with single tree plots. Bottomland blocks contained 9 or 12 seedlings and upland blocks contained 5 or 24 seedlings (Table 2). Both bottomland and upland blocks included multiple species and families (Table 2). The bottomland studies were sorted from the bottomland oak species: swamp chestnut oak, bur oak, water oak, cherrybark oak, Nuttall oak, Shumard oak and willow oak. Some species were not placed in each study due to limited seedling availability. Each

Table 2 – Species and family composition of planting stock at each site.

Site	Seedlings	Blocks	Seedlings/ Block	Species	
Wallace Johnston Tree Farm - Southern Field	4210	354	12	Water oak Cherrybark oak Shumard oak	Nuttall oak Willow oak Swamp chestnut oak
Wallace Johnston Tree Farm - Northern Field	826	69	12	Water oak Cherrybark oak Shumard oak	Willow oak Swamp chestnut oak
FWS Lower Hatchie NWR - Champion Lake	1404	156	9	Water oak Cherrybark oak Shumard oak	Willow oak Nuttall oak
TWRA Moss Island WMA	1730	144	12	Water oak Cherrybark oak Swamp chestnut oak	Willow oak Nuttall oak Bur oak
Strawberry Plains Audubon Center	780	43	24	Black oak Pin oak White oak	Southern red oak Black walnut
FWS Lower Hatchie NWR - Upland	508	43	24	Black oak Pin oak White oak	Southern red oak Black walnut
Pat Estes Tree Farm	300	60	5	Northern red oak	

block received species according to species availability (Table 2) and silvical characteristics. Blocks were divided into two moisture regimes ("wet" or "dry") by observing ponded water or topographic highs and lows. The dry blocks received a mixture of the less flood tolerant species while the wet blocks received the more flood tolerant species.

The upland studies were sorted from the following species: black walnut, southern red oak, pin oak, black oak, white oak, and pecan (Table 2). Each block received each species with the exception of black walnut. Black walnut was placed in alternating blocks to minimize any allelopathic effect on the other seedlings. Blocks received a minimum of two species and at least two families per species. Originally, white oak and common persimmon were incorporated into the design, but planting was delayed until the spring of 2004. White oak was incorporated into the studies in the spring of 2004, but common persimmon was not available for planting. Pecan, instead, will be incorporated during the spring of 2005.

All plantation sites were prepared for planting in late January and early February of 2003 by placing a flag for each seedling planting location. During the winter and early spring of 2003, studies were established in an alley cropping design by combining rows of trees and a crop (Hodge et al., 1999). For the length of the tree rows, there were three seedlings across the width, with the center offset, at ten foot spacing with a five-foot buffer between the outer seedlings and the crop row, except at PE (Figure 1). The tree rows and crop rows were 30 feet wide (Figure 1). The Pat Estes site was designed on a ten-foot tree spacing. Gasoline-powered hand augers with eight inch bits were used to

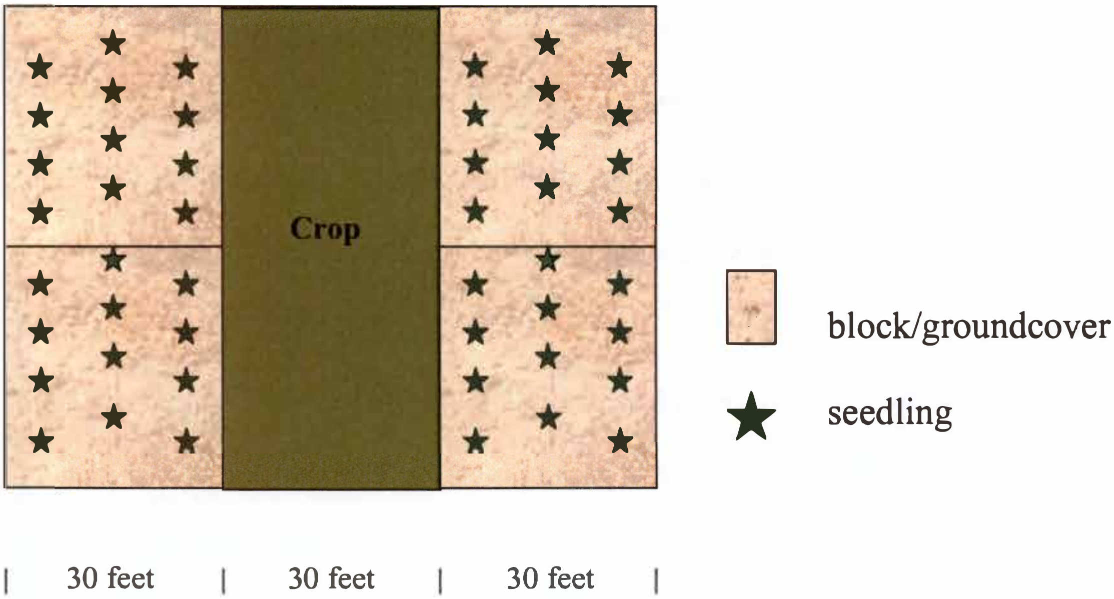

Figure 1 - Sample layout of alley cropping design.

drill holes to a depth of approximately 30 cm, and the seedlings were planted by hand. Studies were then mapped by tag number.

Groundcover and Crops

Browntop millet (*Panicum ramosum*) was broadcast, at 30 pounds per acre, after the plantation establishment in order to minimize volunteer competition and improve the wildlife habitat. The MI site was replanted in Japanese millet [*Echinochloa esculenta* (A. Braun) H. Scholz] after extensive mortality due to late-season flooding. The millets were chosen because of their moderate flood tolerance and heavy production of seed which is used as food by wildlife and for propagation.

The upland tree rows at the AC received one of two treatments, either broadcasted yellow sweetclover (*Melilotus officinalis* L.), at 15 pounds per acre, or browntop millet at 30 pounds per acre. Yellow sweetclover was chosen as a groundcover because of a deep rooting habit and leguminous nature that can enrich the soil with nitrogen. The upland tree rows at the LH – UP site received one of three treatments due to the fact that winter wheat (*Triticum aestivum* L.) was present. Rows were either planted in yellow sweetclover at establishment (after applying glyphosate to the winter wheat), browntop millet on top of the winter wheat when it began to die in June, or the winter wheat was left untouched with no additional seed.

Soybeans were planted on the WJ – S, LH – CL, and LH – UP sites in May and June. A browntop millet/sunflower mixture was planted as the crop on the AC study site. Soybeans were planned for the WJ - N site, but not established due to inaccessibility with the farm equipment due to continued erosion at a stream crossing. The crop alleys were disked, but otherwise left fallow. The 30 foot crop rows on the Moss Island site were not wide enough for passage of the farm equipment. Inaccurate information indicated that the farmer possessed equipment that would fit a 30 foot crop row. A crop was not planted on the Pat Estes site due to alternate demands on the landowner, and the tall fescue (*Festuca arundinacea*) present was mowed twice during the year.

Farming practices on the WJ – S site were the same as previous years except for the inability to cross disk the field prior to planting or create drainages for the removal of water. The LH – CL and LH - UP sites were converted to a no-tillage management for the 2003 crop. Soybeans were planted over approximately 60 percent of each field.

Measurements

The trees were evaluated (Table 3) in May of 2003, with the exception of the LH - CL and MI sites. Recording of tree damage occurred on these bottomland sites in June, due to backwater flooding in May. Seedlings that died back were clipped down to the live portion of the stem at all sites. Sites were visited again in November of 2003 to record live height, damage codes and survival.

Soil Analysis

A soil survey of the sites was conducted during the summer of 2003 to determine possible influences on seedling growth and survival. Soil samples were collected with a

Table 3 - Tree Damage Codes used by the University of Tennessee's Tree Improvement Program.

Tree Damage Codes		
T	1	Broken Top
	2	Dead Top
	3	Terminal Bud Dead
	4*	< 50% Of Stem Height Is Dead
	5*	> 50% Of Stem Height Is Dead
S	1	Sprout Above Root Collar
	2	Sprout At Root Collar
	3*	Beginning to Leaf Out
B	1	Deer Browsed
	2	Rabbit / Groundhog Browsed
	3	Deer Rub
	4	Voles / Wood Rats
	5	Beaver
I	1	White Pine Weevil
	2	Tip Moth (or tip killed by insect)
	3	Stem Borers
	4	Defoliation By Insects
	5	Pine Web Worm
	6	Scale
D	1	Chlorotic
	2	Blights, Cankers
	3	Main Stem Galls
	4	Air Pollution Damage
F	1	Forked Below DBH
	2	Forked Above DBH (in first log)
	3	Forked Above DBH (in second log)
C	1	Crook
	2	Sweep
V	1	Vehicle Damage
	2	Mechanical Damage (farm machinery)
	3	Theft
	4	Vine Damage
H	1	Herbicide Damage
X	1	Terrible Form
W	1	Water Damage (poor drainage, erosion)
L	1*	No Leaves On Live Stem During Growing Season

* Damage codes created for this study.

bucket auger. Soil was collected to a depth sufficient to classify the soil series and determine the depth to redoximorphic features (DTRF). The depth to redox depletions were considered the DTRF for this study. Redox depletions are zones of low chroma (2 or less) where iron and/or manganese oxides have been stripped out of the soil. The DTRF was measured as an indicator of the seasonal high water table and therefore an indicator of low soil redox potentials (West et al., 1998). The texture and color of each horizon were recorded as well as the DTRF observed. Soil pH was analyzed in the field using a Hellige™ soil reaction pH tester with a resolution of 0.5 pH units. Samples were collected as intensively and in a pattern as deemed necessary to accurately represent the study site and to create a soil wetness map. Composite soil samples were randomly collected to a depth of 15 cm within "management areas." Management areas were portions of the study sites that were sufficiently homogeneous, by visual inspection, in regards to topography, soil, and moisture to suggest that the soil nutrient status may be similar. The composite samples were sent to A&L Laboratories in Memphis, Tennessee for analysis of extractable nutrients, soil organic matter, and pH in order to establish baseline fertility measurements that could be used to explain differences in seedling species performance.

GPS/GIS & Elevation Survey

Relative elevation points were surveyed on the MI and LH - CL sites to relate seedling growth to flood severity and extent (McLeod et al., 2000). An engineer's level and Philadelphia rod were used to conduct a differential leveling survey. A benchmark of 100 feet was assumed at an arbitrary location on each site. All elevations were measured relative to the benchmark.

A handheld Trimble® GeoExplorer Global Positioning System (GPS) unit was used to map the blocks and perimeter of each site. Wide Area Augmentation System was used when available to increase accuracy by real-time differential correction. GPS data were then differentially corrected by post processing from the nearest operational base station in Franklin, Tennessee (approximately 200 miles from the sites). Sample locations and measured values of both DTRF and relative elevation were then used to create a raster dataset. The raster surface was produced using the tension spline method available in ArcMap™ version 8.3 (ESRI, 1999-2002). Combining the block/perimeter feature themes and rasters produced a map of the sites with the associated elevation and/or DTRF. The block feature layer of each site was then used with zonal statistics to obtain a mean value of DTRF and relative elevation for each block.

Economics

Available financial records were collected from farmers regarding the costs and revenues of farming the sites in recent years and the first year of alley cropping. Costs associated with seedling establishment (design layout, seedlings, and labor) were calculated. Financial information was gathered only on sites producing a soybean crop for the 2003 growing season. Financial information was pooled and estimates were created for the average cost of alley cropping establishment and first year crop production on these sites.

Data

Analyses on survival, damage, and initial seedling measurements were conducted on datasets that contained only seedlings of known genetic identity. Analyses of height growth and basal sprouting were conducted on datasets where seedlings of unknown genetic identity, broken stems, forked stems, or seedlings that did not survive the first year were eliminated. Bottomland regression analysis was performed on a dataset that contained all bottomland studies combined as well as a dataset that just combined the flooded studies (LH-CL and MI). The latter dataset allowed flood depth to be incorporated in to the model. Upland regression analysis was performed on a combined dataset of all study sites. Dummy regression was utilized to determine the statistical validity of combining site datasets for regression analysis.

Statistical Analyses

Means of initial height, RCD, and FOLR for planted seedlings in each species were calculated. Means were then compared to the species sample means to determine the relative quality of planted seedlings. Pearson correlations were conducted on variables of interest to further investigate relationships. An error level of $\alpha = 0.05$ was used to indicate significant differences for all analysis.

Data that violated basic assumptions of ANOVA and regression analysis were rank transformed (Conover and Iman, 1981). When data was rank transformed in ANOVA and regression analyses, mean separation and parameter estimates, respectively, were reported from analysis of untransformed data .

The data were analyzed using the statistical software SAS version 9.1 (SAS, 2002-2003). A mixed model was used to analyze the data with two treatment factors, species and family, with covariates. Analysis of variance (ANOVA) was used to detect significant differences in initial seedling measurements, survival, growth, and damage among species and families within species. ANOVA was also conducted using a split-plot treatment design on the WJ-S site to detect interactions between species height growth and the depth to redoximorphic features (DTRF). DTRF was used as the whole-plot with ranges of 5 cm and species were the sub-plot. Survival and damage were coded as 0 or 1 for analysis. Fisher's Protected Least Significant Difference (LSD) test was used to identify significant differences among species and families. Stepwise variable selection was used to select covariates from site and seedling variables for each ANOVA.

For bottomland sites, logistic regression was conducted to detect relationships between the initial seedling measurements and site parameters and subsequent seedling survival, sprouting, and deer browse for each species. Multiple regression analysis was also conducted in order to detect relationships between height growth and initial seedling measurements and site parameters for each species. An additional multiple regression analysis was conducted to account for the presence of absence of submerging floods by utilizing a class variable of flood represented by a 1 or 0. The importance of independent variables in explaining a dependent variable was measured by the probability value for all regression analyses. Stepwise variable selection was used to select significant independent variables.

For upland sites, logistic regression was conducted to detect relationships between initial seedling measurements and site parameters on subsequent seedling survival and deer browse for each species. Multiple regression analysis was also conducted on upland datasets to detect relationships between height growth and initial seedling measurements and site parameters for each species.

CHAPTER IV.

RESULTS

Flooding

The first growth flush on the bottomland sites (WJ–S, WJ–N, LH–CL, and MI) were affected by various intensities of flooding or soil saturation. Ponding of rain water less than eight inches deep occurred over the majority of the WJ–S and WJ–N sites. This ponding fluctuated, but extended into the month of June 2003. Depth to redoximorphic features (DTRF) ranged from 0 to 40 cm across the two sites and were generally closer to the soil surface where the ponded water remained for longer periods of time (Figure 2 and 3).

The LH – CL and MI sites were subjected to severe flood events. Flood depths ranged from 0 to 7 feet on the LH–CL site and 6 to 12 feet on the MI site (Figure 4 and 5). On May 10, 2003 backwater flooding began to fill the lower portions of the LH–CL site. Floodwaters began to completely submerge the lowest seedlings in the field by May 16; and on May 20, the floodwaters crested and submerged all but the highest seedlings in the field. By May 29, floodwaters receded and submerged only the lowest seedlings. Only slight ponding remained in the lowest portions of the field on June 3. Accounts of flooding on the MI site are limited to the cresting of floodwaters, but increased flood depths indicate that the MI site was flooded for a greater period of time than the LH–CL site. The DTRF ranged from 0 to 23 cm for the LH – CL site, and 0 to 4 cm for the MI site (Figure 6 and 7).

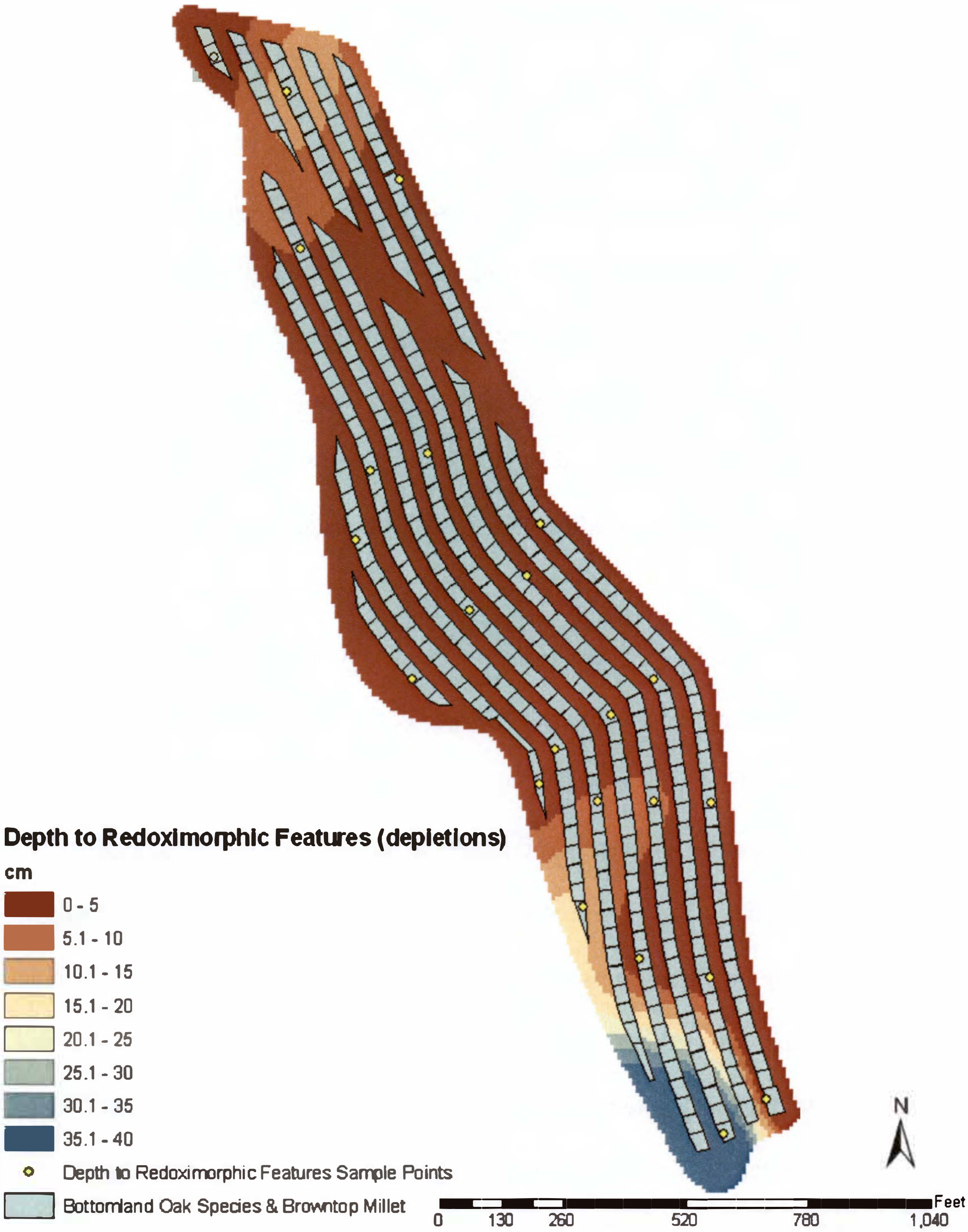

Figure 2 – Depth to redoximorphic feature map of Wallace Johnston - Southern Field.

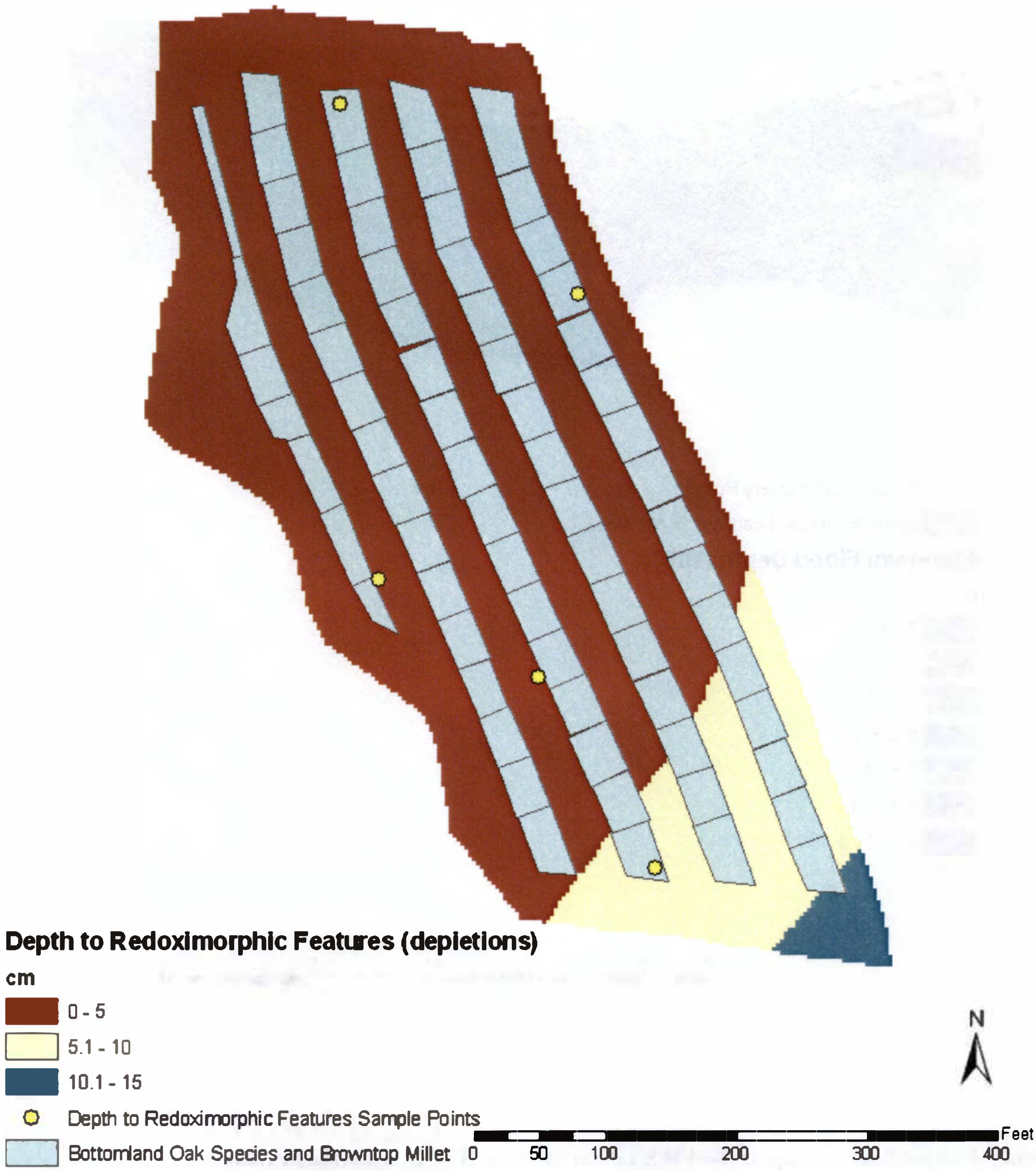

Figure 3 – Depth to redoximorphic feature map of Wallace Johnston – Northern Field.

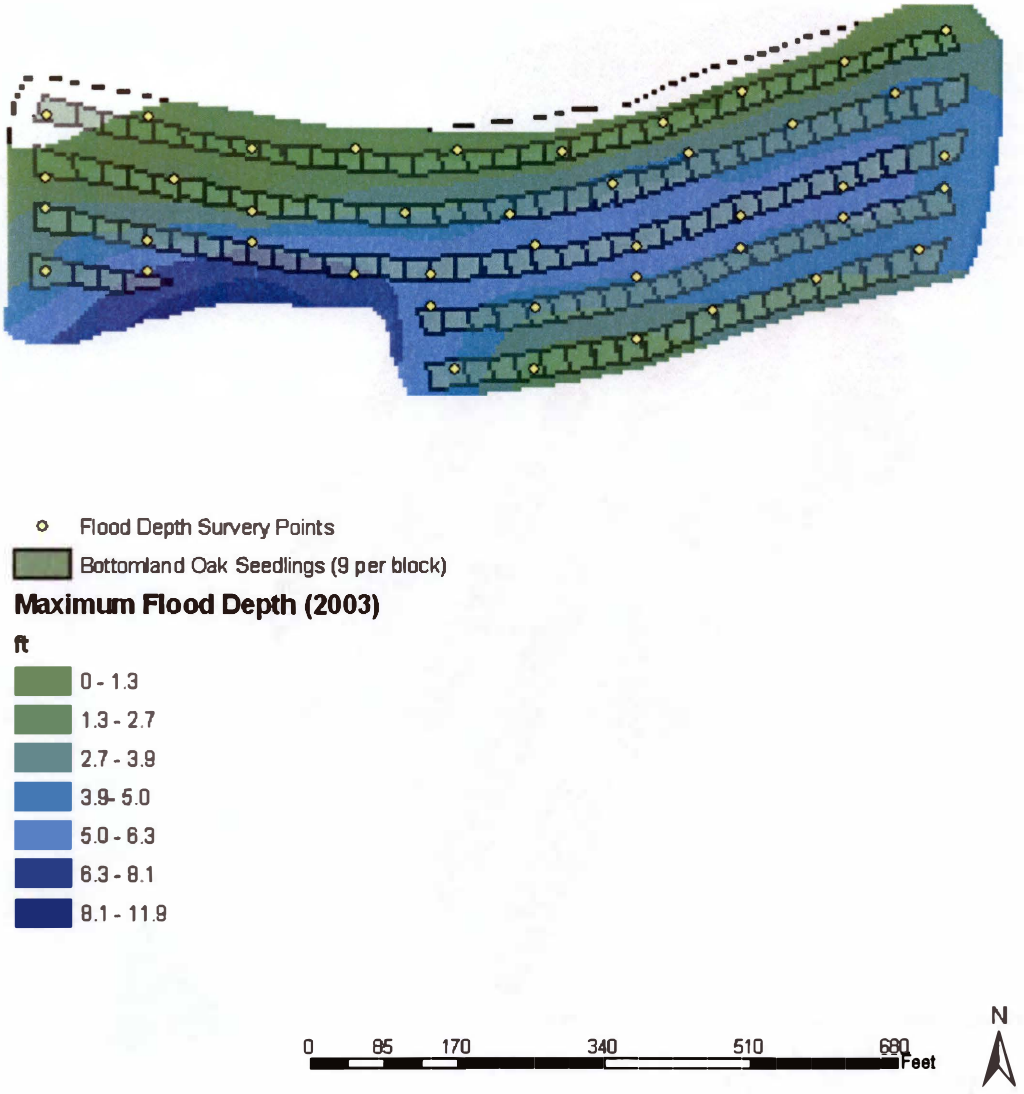

Figure 4 – Flood depth map of the FWS Lower Hatchie NWR – Champion Lake.

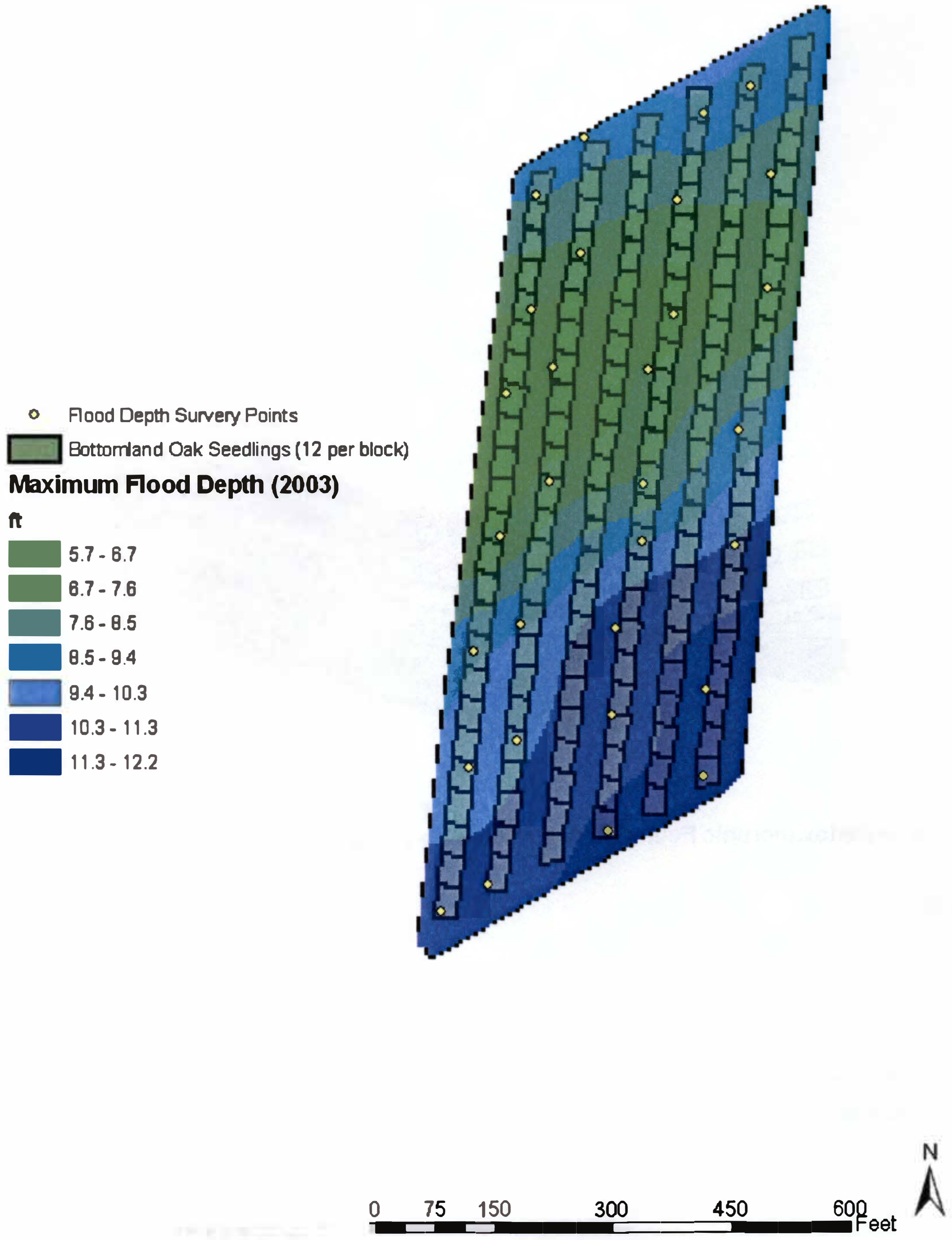

Figure 5 – Flood depth map of TWRA Moss Island WMA.

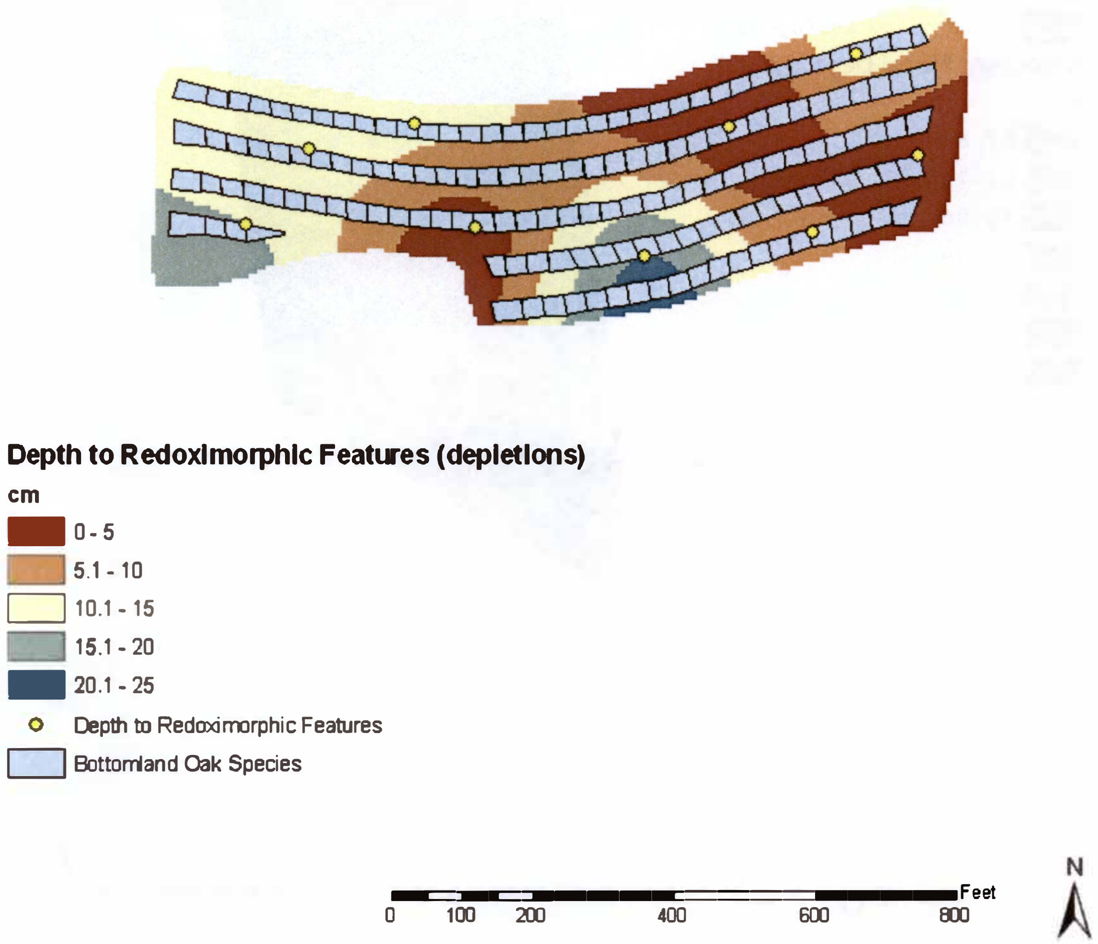

Figure 6 - Depth to redoximorphic feature map of FWS Lower Hatchie NWR – Champion Lake.

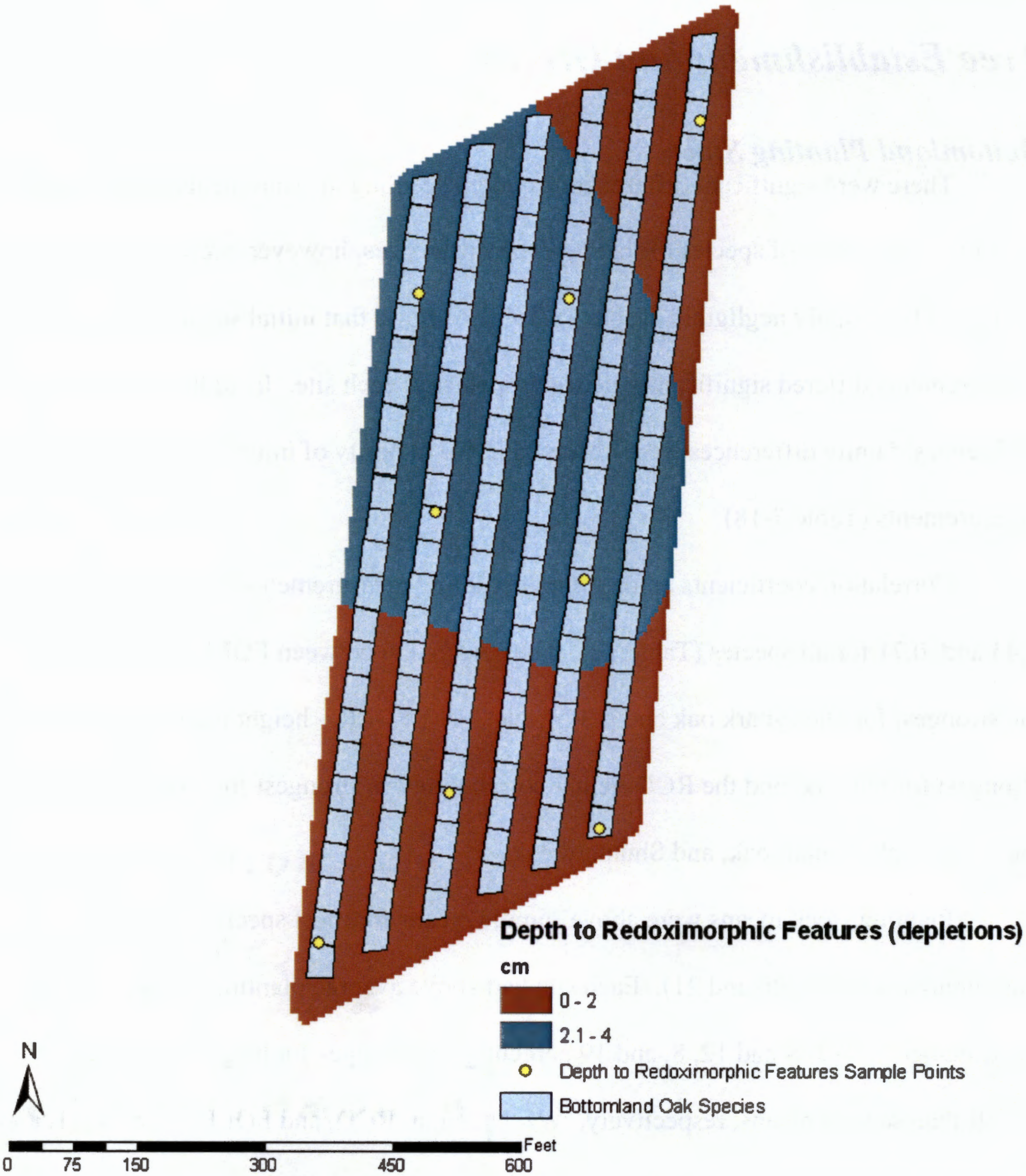

Figure 7 - Depth to redoximorphic feature map of TWRA Moss Island WMA.

Flood depth and soil characteristics/nutrients exhibited a generally strong relationship (Table 4). DTRF and flood depth had a moderate to strong relationship where increasing flood depth was associated with redoximorphic features closer to the soil surface.

Tree Establishment and Growth

Bottomland Planting Stock

There were significant differences in initial seedling measurements across study sites for the majority of species (Table 5). The differences, however, were often small enough to be visually negligible (Table 5). Table 6 shows that initial seedling measurements differed significantly between species at each site. In addition to species differences, family differences were observed in the majority of initial seedling measurements (Table 7-18).

Correlation coefficients among initial seedling measurements ranged between 0.43 and 0.71 for all species (Table 19). The correlation between FOLR and RCD was the strongest for cherrybark oak and willow oak. The FOLR – height relationship was strongest for bur oak; and the RCD-height correlation was strongest for swamp chestnut oak, water oak, Nuttall oak, and Shumard oak.

Planting stock means were above sample means for most species and initial measurements (Table 20 and 21). Each site had above average planting stock measurements. WJ–S had 12, 8, and 19 percent greater values for height, RCD, and FOLR than sample means, respectively. WJ–N height, RCD, and FOLR were 15, 11, and 55 percent higher than sample means, respectively. LH–CL had planting stock that

Table 4 – Pearson correlation coefficients comparing the relationship between flood depth and the collected soil parameters for the two flooded sites, FWS Lower Hatchie NWR – Champion Lake and TWRA Moss Island WMA (n=3003).

	Flood Depth	p-value
Calcium	0.85	<0.0001
Magnesium	0.84	<0.0001
Copper	0.83	<0.0001
CEC	0.83	<0.0001
Zinc	0.82	<0.0001
Sodium	0.81	<0.0001
Potassium	0.81	<0.0001
Organic matter	0.76	<0.0001
Phosphorous	-0.72	<0.0001
Sulfur	-0.69	<0.0001
DTRF	-0.69	<0.0001
Buffer pH	-0.47	<0.0001
pH	0.45	<0.0001
Boron	0.37	<0.0001
Iron	-0.37	<0.0001
Manganese	-0.16	<0.0001

Table 5 – Mean initial height, mean initial root collar diameter, and mean number of initial first order lateral roots of planting stock for the four bottomland studies.

	Species (observations)	Wallace Johnston Tree Farm - Southern Field	Wallace Johnston Tree Farm - Northern Field	FWS Lower Hatchie NWR - Champion Lake	TWRA Moss Island	ANOVA P-Value
Initial Height (cm)	Cherrybark oak (1133)	109.93 B[1]	111.5 AB	112.23 AB	113.3 A	0.0429
	Bur oak (72)	NA	NA	NA	88.34	NA
	Swamp chestnut oak (500)	111.86 A	114.39 A	NA	108.41 A	0.0601
	Water oak (2584)	110.72 B	112.8 AB	112.32 AB	112.82 A	0.0297
	Nuttall oak (833)	130.16 A	NA	125 B	120.56 C	<0.0001
	Willow oak (2303)	103.18 B	101.91 B	115.57 A	114.08 A	<0.0001
	Shumard oak (392)	131.35 A	126.15 A	122.32 A	NA	0.0529
Initial Root Collar Diameter (mm)	Cherrybark oak	9.75 A	9.84 A	9.62 A	9.2 B	0.0001
	Bur oak	NA	NA	NA	13.41	NA
	Swamp chestnut oak	13.2 A	13.13 A	NA	11.6 B	<0.0001
	Water oak	9.67 B	9.74 AB	9.64 B	9.9 A	0.0225
	Nuttall oak	13.28 A	NA	12.32 B	12.59 B	0.0004
	Willow oak	9.47 C	9.14 D	10.19 A	9.86 B	<0.0001
	Shumard oak	11.37 A	11.48 A	8.9 B	NA	<0.0001
# Initial First Order Lateral Roots	Cherrybark oak	7.24 A	7.42 A	7.58 A	8.19 A	0.0846
	Bur oak	NA	NA	NA	21.76	NA
	Swamp chestnut oak	14.39 B	16.72 A	NA	12.51 C	<0.0001
	Water oak	4.95 B	5.64 A	4.95 B	5.09 B	0.041
	Nuttall oak	12.15 A	NA	11.71 A	10.42 B	0.0032
	Willow oak	4.03 B	4.43 B	5.18 A	5.02 A	<0.0001
	Shumard oak	13.14 A	11.98 AB	9.57 B	NA	0.0148

[1] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha=0.05 level.

Table 6 – Species differences in mean initial height, mean initial root collar diameter, and mean number of initial first order lateral roots of planting stock for the four bottomland studies.

Site	Species (observations)	Initial Height (cm)	Initial Root Collar Diameter (mm)	Initial Number of First Order Lateral Roots
Wallace Johnston Tree Farm - Southern Field	cherrybark oak (527)	109.93 B[1]	9.76 C	7.24 D
	swamp chestnut oak (189)	111.86 B	13.20 A	14.39 A
	water oak (1406)	110.72 B	9.68 C	4.95 E
	Nuttall oak (252)	130.16 A	13.28 A	12.15 C
	willow oak (1406)	103.18 C	9.47 D	4.03 F
	Shumard oak (289)	131.35 A	11.38 B	13.15 B
	p-value	<0.0001	<0.0001	<0.0001
	n	4069	4069	4069
Wallace Johnston Tree Farm - Northern Field	cherrybark oak (121)	111.5 B[1]	9.843 C	7.4298 C
	swamp chestnut oak (84)	114.39 B	13.131 A	16.7262 A
	water oak (250)	112.8 B	9.74 C	5.64 D
	willow oak (253)	101.91 C	9.1415 D	4.4308 E
	Shumard oak (75)	126.15 A	11.4813 B	11.9867 B
	p-value	<0.0001	<0.0001	<0.0001
	n	783	783	783
FWS Lower Hatchie NWR - Champion Lake	cherrybark oak	112.23 C[1]	9.6229 C	7.5843 C
	water oak	112.32 C	9.6415 C	4.9531 D
	Nuttall oak	125 A	12.3265 A	11.7165 A
	willow oak	115.57 B	10.1942 B	5.189 D
	Shumard oak	122.32 AB	8.9 C	9.5714 B
	p-value	<0.0001	<0.0001	<0.0001
	n	1345	1345	1345
TWRA Moss Island WMA	cherrybark oak (218)	113.3 B[1]	9.2041 E	8.1927 D
	bur oak (72)	88.3472 D	13.4194 A	21.7639 A
	swamp chestnut oak (227)	108.41 C	11.6013 C	12.5198 B
	water oak (587)	112.82 B	9.9087 D	5.0971 E
	Nuttall oak (199)	120.56 A	12.5985 B	10.42 C
	willow oak (317)	114.08 B	9.8618 D	5.0284 E
	p-value	<0.0001	<0.0001	<0.0001
	n	1621	1621	1621

[1] Mean separation by Fisher's protected least significant difference tests (LSD). Means within a site and column followed by the same letter are not significantly different at the alpha=0.05 level.

Table 7 – ANOVA results comparing mean initial height among families with associated family mean and range for the Wallace Johnston Tree Farm – Southern Field.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Cherrybark oak (28)	111.1	85.3 - 125.3	5.8	<0.0001
Swamp chestnut oak (4)	109.2	102.8 - 117.1	3.2	0.0042
Water oak (45)	108.5	54.0 - 131.4	3.6	<0.0001
Nuttall oak (13)	130.1	120.3 - 146.0	5.4	0.0394
Willow oak (36)	100.5	73.0 - 121.5	3.2	<0.0001
Shumard oak (5)	129.1	116.3 - 146.2	2.8	<0.0001

Table 8 - ANOVA results comparing mean initial root collar diameter among families with associated family mean and range for the Wallace Johnston Tree Farm – Southern Field.

Species (# families)	Family Mean (mm)	Family Range (mm)	Mean SE	Family P-Value
Cherrybark oak (28)	10.4	8.6 - 14.9	0.5	<0.0001
Swamp chestnut oak (4)	12.8	11.0 - 14.5	0.43	<0.0001
Water oak (45)	9.6	5.4 - 11.6	0.4	<0.0001
Nuttall oak (13)	13.6	10.5 - 18.6	0.6	<0.0001
Willow oak (36)	9.3	6.8 - 11.0	0.3	<0.0001
Shumard oak (5)	11.4	10.5 - 12.1	0.2	<0.0001

Table 9 - ANOVA results comparing mean initial first order lateral roots among families with associated family mean and range for the Wallace Johnston Tree Farm – Southern Field.

Species (# families)	Family Mean	Family Range	Mean SE	Family P-Value
Cherrybark oak (28)	7.8	3.5 - 13.0	1.4	<0.0001
Swamp chestnut oak (4)	16.4	11.4 - 21.6	1.1	<0.0001
Water oak (45)	4.9	0 - 11.0	0.8	<0.0001
Nuttall oak (13)	13.1	9.0 - 23.0	1.5	<0.0001
Willow oak (36)	3.9	0 - 7.0	0.6	<0.0001
Shumard oak (5)	13	5.4 - 19.2	0.7	<0.0001

Table 10 - ANOVA results comparing mean initial height among families with associated family mean and range for the Wallace Johnston Tree Farm – Northern Field.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Cherrybark oak (9)	111.8	102.3 - 119.8	4.4	0.1863
Swamp chestnut oak (4)	112.8	87.1 - 130.2	4	<0.0001
Water oak (15)	113.7	93.6 - 129.5	4.3	<0.0001
Willow oak (9)	103.3	89.5 - 130.5	3.1	<0.0001
Shumard oak (5)	127.3	110.2 - 145.8	6.1	0.0002

Table 11 - ANOVA results comparing mean initial root collar diameter among families with associated family mean and range for the Wallace Johnston Tree Farm – Northern Field.

Species (# families)	Family Mean (mm)	Family Range (mm)	Mean SE	Family P-Value
Cherrybark oak (9)	9.9	8.9 - 11.1	0.4	0.0028
Swamp chestnut oak (4)	13.3	11.4 - 15.1	0.6	0.0004
Water oak (15)	9.8	8.6 - 11.7	0.5	0.035
Willow oak (9)	9.3	8.2 - 11.0	0.3	0.0002
Shumard oak (5)	11.3	9.2 - 12.5	0.6	0.0057

Table 12 - ANOVA results comparing mean initial first order lateral roots among families with associated family mean and range for the Wallace Johnston Tree Farm – Northern Field.

Species (# families)	Family Mean	Family Range	Mean SE	Family P-Value
Cherrybark oak (9)	7.4	5.0 - 9.9	1.2	0.0805
Swamp chestnut oak (4)	16.2	11.6 - 23.2	1.6	<0.0001
Water oak (15)	5.9	2.5 - 14.0	1	<0.0001
Willow oak (9)	4.5	2.2 - 6.2	0.6	<0.0001
Shumard oak (5)	12.4	5.1 - 19.6	1.3	<0.0001

Table 13 - ANOVA results comparing mean initial height among families with associated family mean and range for the FWS Lower Hatchie NWR – Champion Lake.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Cherrybark oak (17)	111.6	94.4 - 120.4	4.9	0.0922
Water oak (32)	110.6	95.0 - 129.0	6.4	0.0235
Nuttall oak (10)	124.9	106.5 - 134.6	4.6	<0.0001
Willow oak (18)	113.9	101.2 - 127.5	4.1	<0.0001
Shumard oak (2)	119	113.2 - 124.8	6.3	0.223

Table 14 - ANOVA results comparing mean initial root collar diameter among families with associated family mean and range for the FWS Lower Hatchie NWR – Champion Lake.

Species (# families)	Family Mean (mm)	Family Range (mm)	Mean SE	Family P-Value
Cherrybark oak (17)	9.6	7.5 - 11.5	0.5	<0.0001
Water oak (32)	9.6	8.5 - 11.8	0.6	<0.0001
Nuttall oak (10)	12.5	9.4 - 14.4	0.6	<0.0001
Willow oak (18)	10.1	8.9 - 11.1	0.4	0.0024
Shumard oak (2)	8.9	8.8 - 8.9	0.3	0.8534

Table 15 - ANOVA results comparing mean initial first order lateral roots among families with associated family mean and range for the FWS Lower Hatchie NWR – Champion Lake.

Species (# families)	Family Mean	Family Range	Mean SE	Family P-Value
Cherrybark oak (17)	7.8	4.3 - 10.7	1.6	0.0306
Water oak (32)	4.7	2.0 - 7.7	1.4	0.0124
Nuttall oak (10)	11.1	6.5 - 15.6	1.2	<0.0001
Willow oak (18)	5.3	2.5 - 7.7	0.9	<0.0001
Shumard oak (2)	9.2	8.7 - 9.8	1.2	0.5357

Table 16 - ANOVA results comparing mean initial height among families with associated family mean and range for the TWRA Moss Island WMA.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Cherrybark oak (13)	109.8	75.0 - 124.1	5.5	<0.0001
Bur oak (2)	89	81.0 - 97.0	3	0.0003
Swamp chestnut oak (3)	106.1	97.7 - 112.1	2.5	0.0014
Water oak (24)	105.9	45.0 - 124.7	6.5	<0.0001
Nuttall oak (8)	119.5	108.0 - 131.7	3.9	<0.0001
Willow oak (11)	114.3	105.5 - 125.1	3.3	<0.0001

Table 17 - ANOVA results comparing mean initial root collar diameter among families with associated family mean and range for the TWRA Moss Island WMA.

Species (# families)	Family Mean (mm)	Family Range (mm)	Mean SE	Family P-Value
Cherrybark oak (13)	9.1	8.2 - 10.1	0.6	<0.0001
Bur oak (2)	13.4	13.2 - 13.7	0.5	0.4289
Swamp chestnut oak (3)	11.2	9.4 - 12.4	0.3	<0.0001
Water oak (24)	9.6	7.0 - 11.5	0.6	<0.0001
Nuttall oak (8)	12.8	10.6 - 17.1	0.5	<0.0001
Willow oak (11)	10.1	9.2 - 11.9	0.4	0.0031

Table 18 - ANOVA results comparing mean initial first order lateral roots among families with associated family mean and range for the TWRA Moss Island WMA.

Species (# families)	Family Mean	Family Range	Mean SE	Family P-Value
Cherrybark oak (13)	7.9	2.0 - 15.7	2	0.002
Bur oak (2)	21.8	21.4 - 22.2	1.2	0.65
Swamp chestnut oak (3)	11.4	8.2 - 15.3	0.8	<0.0001
Water oak (24)	4.9	1.0 - 9.0	1.3	<0.0001
Nuttall oak (8)	10.4	8.2 - 14.7	1	0.0013
Willow oak (11)	4.8	2.5 - 6.2	0.6	<0.0001

Table 19 – Correlation coefficients for initial seedling measurements of bottomland samples.

	FOLR-RCD	FOLR-Height	Height-RCD
Cherrybark oak	0.71	0.55	0.65
Bur oak	0.56	0.64	0.58
Swamp chestnut oak	0.45	0.45	0.48
Water oak	0.69	0.52	0.71
Nuttall oak	0.48	0.54	0.57
Willow oak	0.66	0.43	0.56
Shumard oak	0.62	0.57	0.63

All correlation values are significant at alpha=0.05

Table 20 – Comparison of planted and lifted seedlings to indicate relative planting stock quality for Wallace Johnston Tree Farm – Southern and Northern Fields.

Field	Seedling Measurement	Species	.... Planted .... Mean	n	.... Lifted .... Mean	n	Planted vs. Lifted (% difference)
Wallace Johnston Tree Farm - Southern Field	Initial Height (cm)	cherrybark oak	109.93	527	100	2496	9.93
		swamp chestnut oak	111.86	189	97.37	486	14.88
		water oak	110.72	1406	95.87	6078	15.49
		Nuttall oak	130.16	252	125.21	811	3.95
		willow oak	103.18	1406	95.27	3953	8.30
		Shumard oak	131.35	289	112.77	275	16.48
							Mean Difference = 11.51%
	Initial Root Collar Diameter (mm)	cherrybark oak	9.76	527	9.01	2496	8.31
		swamp chestnut oak	13.20	189	11.53	486	14.53
		water oak	9.68	1406	8.57	6078	12.90
		Nuttall oak	13.28	252	13.51	811	-1.67
		willow oak	9.47	1406	9.13	3953	3.78
		Shumard oak	11.38	289	10.21	275	11.45
							Mean Difference = 8.21%
	Number of Initial First Order Lateral Roots	cherrybark oak	7.24	527	4.86	2496	49.03
		swamp chestnut oak	14.39	189	11.59	486	24.17
		water oak	4.95	1406	3.75	6078	32.02
		Nuttall oak	12.15	252	12.09	811	0.54
		willow oak	4.03	1406	3.81	3953	5.90
		Shumard oak	13.15	289	12.75	275	3.13
							Mean Difference = 19.13%
			Overall Mean Difference = 12.95%				
Wallace Johnston Tree Farm - Northern Field	Initial Height (cm)	cherrybark oak	111.50	121	102.84	1293	8.42
		swamp chestnut oak	114.39	84	95.07	307	20.32
		water oak	112.80	250	98.14	2198	14.94
		willow oak	101.91	253	93.63	1527	8.84
		Shumard oak	126.15	75	104.26	183	21.00
							Mean Difference = 14.70%
	Initial Root Collar Diameter (mm)	cherrybark oak	9.84	121	9.13	1293	7.81
		swamp chestnut oak	13.13	84	11.67	307	12.52
		water oak	9.74	250	8.59	2198	13.39
		willow oak	9.14	253	8.79	1527	4.00
		Shumard oak	11.48	75	9.8	183	17.16
							Mean Difference = 10.97%
	Number of Initial First Order Lateral Roots	cherrybark oak	7.43	121	4.88	1293	52.25
		swamp chestnut oak	16.73	84	9.97	307	67.77
		water oak	5.64	250	3.57	2198	57.98
		willow oak	4.43	253	3.55	1527	24.81
		Shumard oak	11.99	75	6.91	183	73.47
							Mean Difference = 55.26%
			Overall Mean Difference = 26.98%				

Table 21 - Comparison of planted and lifted seedlings to indicate relative planting stock quality for FWS Lower Hatchie NWR – Champion Lake and TWRA Moss Island WMA.

	Seedling Measurement	Species	.... Planted .... Mean	n	.... Lifted .... Mean	n	Planted vs. Lifted (% difference)
FWS Lower Hatchie NWR - Champion Lake	Initial Height (cm)	cherrybark oak	112.23	267	102.27	2205	9.74
		water oak	112.32	341	97.28	5064	15.46
		Nuttall oak	125.00	381	124.47	929	0.43
		willow oak	115.57	328	97.66	3444	18.34
		Shumard oak	122.32	28	120.09	174	1.86
							Mean Difference = 9.16%
	Initial Root Collar Diameter (mm)	cherrybark oak	9.62	267	8.94	2205	7.64
		water oak	9.64	341	8.56	5064	12.63
		Nuttall oak	12.33	381	12.64	929	-2.48
		willow oak	10.19	328	9.09	3444	12.15
		Shumard oak	8.90	28	10.12	174	-12.06
							Mean Difference = 3.58%
	Number of Initial First Order Lateral Roots	cherrybark oak	7.58	267	3.78	2205	100.64
		water oak	4.95	341	4.06	5064	22.00
		Nuttall oak	11.72	381	11.87	929	-1.29
		willow oak	5.19	328	4.03	3444	28.76
		Shumard oak	9.57	28	10.5	174	-8.84
							Mean Difference = 28.25%
			Overall Mean Difference = 13.66%				
TWRA Moss Island WMA	Initial Height (cm)	cherrybark oak	113.30	218	100.94	1527	12.24
		bur oak	88.35	72	85.71	133	3.08
		swamp chestnut oak	108.41	227	99.73	410	8.70
		water oak	112.82	587	95.73	4218	17.85
		Nuttall oak	120.56	200	123.34	681	-2.25
		willow oak	114.08	317	98.66	2144	15.63
							Mean Difference = 9.21%
	Initial Root Collar Diameter (mm)	cherrybark oak	9.20	218	8.94	1527	2.95
		bur oak	13.42	72	13.4	133	0.14
		swamp chestnut oak	11.60	227	11.35	410	2.21
		water oak	9.91	587	8.41	4218	17.82
		Nuttall oak	12.60	200	12.98	681	-2.94
		willow oak	9.86	317	8.99	2144	9.70
							Mean Difference = 4.98%
	Number of Initial First Order Lateral Roots	cherrybark oak	8.19	218	5.24	1527	56.35
		bur oak	21.76	72	20.52	133	6.06
		swamp chestnut oak	12.52	227	11.52	410	8.68
		water oak	5.10	587	3.65	4218	39.65
		Nuttall oak	10.42	200	11.7	681	-10.94
		willow oak	5.03	317	3.98	2144	26.34
							Mean Difference = 21.02%
			Overall Mean Difference = 11.74%				

was 9, 4, and 28 percent greater than the sample height, RCD, and FOLR, respectively. MI height, RCD, and FOLR were 9, 5, 21 percent greater than sample means.

Bottomland Survival

Overall seedling survival was 90, 88, 79, and 35 percent for WJ - S, WJ - N, LH - CL, and MI, respectively. Survival differed significantly among species at all sites.

The WJ - S site had the highest survival at 90 percent. Willow oak survival was greater than all other species at 98 percent (Table 22). Nuttall oak survival (91%) was not different from swamp chestnut oak (91%) and Shumard oak (87%) (Table 22). Water oak survival (85%) was less than Nuttall oak, but not different from Shumard oak, swamp chestnut oak, and cherrybark oak (83%) (Table 22). Survival differences were observed in cherrybark oak, water oak, and willow oak families (Table 23).

The WJ – N site had the second best survival at 88 percent. Willow oak and swamp chestnut oak did not differ in survival at 97 and 92 percent, respectively (Table 22). Shumard oak (86%) and cherrybark oak (86%) survival was not different from swamp chestnut oak, but less than willow oak (Table 22). Water oak (79%) survival was less than swamp chestnut oak, but not different from cherrybark oak and Shumard oak (Table 22). Cherrybark oak, water oak, and Shumard oak differed in family survival (Table 24).

The third best survival (79%) was on the LH –CL site. Nuttall oak (88%) and willow oak (87%) had the greatest survival, but they were not different from Shumard oak (74%) (Table 22). Cherrybark oak (71%) and water oak (68%) were not different

Table 22 – Survival estimates for bottomland species by site.

Species	Wallace Johnston Tree Farm - Southern Field[1]		Wallace Johnston Tree Farm - Northern Field[1]		FWS Lower Hatchie NWR - Champion Lake[1]		TWRA Moss Island	
Cherrybark oak	82.82%	D	85.54%	BC	70.83%	B	25.24%	CD
Bur oak	NA		NA		NA		58.16%	A
Swamp chestnut oak	90.76%	BC	91.98%	AB	NA		41.61%	B
Water oak	84.59%	CD	79.08%	C	67.83%	B	22.33%	D
Nuttall oak	90.75%	B	NA		88.36%	A	65.77%	A
Willow oak	97.75%	A	96.78%	A	87.29%	A	33.70%	BC
Shumard oak	87.37%	BC	86.24%	BC	73.63%	AB	NA	
p-value	<0.0001		<0.0001		<0.0001		<0.0001	
observations	4069		783		1345		1621	

[1] p-value and mean separation derived from rank transformed data; estimates are derived from untransformed data

[2] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha=0.05 level.

Table 23 - ANOVA results comparing mean survival among families with associated family mean and range for the Wallace Johnston Tree Farm – Southern Field.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Cherrybark oak (28)	82.6	23.6 - 100	13	0.0011[1]
Swamp chestnut oak (4)	96.2	94.7 - 97.4	3.2	0.7481[1]
Water oak (45)	82.1	11.2 - 100	8.9	<0.0001[1]
Nuttall oak (13)	96.8	82.6 - 100	5.5	0.18[1]
Willow oak (36)	97.4	85.3 - 100	4	<0.0001[1]
Shumard oak (5)	90.6	82.9 - 98.8	4.1	0.5589[1]

[1] p-value is derived from rank transformed data

Table 24 - ANOVA results comparing mean survival among families with associated family mean and range for the Wallace Johnston Tree Farm – Northern Field.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Cherrybark oak (9)	87.2	69.8 - 100	9.8	0.0243[1]
Swamp chestnut oak (4)	97.7	95.8 - 99.7	3.5	0.4849[1]
Water oak (15)	78.8	37.0 - 97.4	11.4	0.0027[1]
Willow oak (9)	94.1	80.3 - 100	4.4	0.4304[1]
Shumard oak (5)	88.3	75.0 - 94.1	8.3	0.0018[1]

[1] p-value is derived from rank transformed data

from each other or Shumard oak (Table 22). Family survival was significantly different in water oak and Nuttall oak (Table 25).

The MI site had the worst overall survival with only 35 percent of the trees living. Nuttall oak and bur oak had greater survival from other species at 66 and 58 percent, respectively (Table 22). Swamp chestnut oak (42%) and willow oak (34%) survival was not different (Table 22). Cherrybark oak (25%) survival did not differ from willow oak, but was less than swamp chestnut oak (Table 22). Water oak (22%) survival did not differ from cherrybark oak, but was less than willow oak (Table 22). Swamp chestnut oak and Nuttall oak had family differences in survival (Table 26).

Influences on Survival

The first group of logistic regression models (model 1) produced rescaled R^2 values for species ranging from 0.12 to 0.52 and included all bottomland sites (Table 27). The second group of logistic regression models (model 2) produced rescaled R^2 values for species that range from 0.19 to 0.41 and included only the LH–CL and MI sites (Table 28). Slopes were not different when comparing sites in both datasets.

Model 1 (all bottomland sites)

An R^2 of 29 percent was produced for cherrybark oak survival. The independent variables are presented in order of decreasing importance: soil potassium, soil organic matter and FOLR, and soil buffer pH. Variables had negative relationships with cherrybark oak survival except FOLR.

Soil calcium had a significant, negative relationship with swamp chestnut oak survival and produced an R^2 of 42 percent.

Table 25 - ANOVA results comparing mean survival among families with associated family mean and range for the FWS Lower Hatchie NWR – Champion Lake.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Cherrybark oak (17)	76.2	43.7 - 100	14	0.0810[1]
Water oak (32)	76.5	37.4 - 100	17.1	0.0099[1]
Nuttall oak (10)	89.6	76.2 - 100	7.5	0.0127[1]
Willow oak (18)	84.3	65.9 - 100	11	0.0614[1]
Shumard oak (2)	71.2	59.1 - 83.4	15.4	*

[1] p-value is derived from rank transformed data

* Infinite likelihood occurred

Table 26 - ANOVA results comparing mean survival among families with associated family mean and range for the TWRA Moss Island WMA.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Cherrybark oak (13)	32.1	3.9 - 91.6	18	0.1064
Bur oak (2)	75.8	69.0 - 82.7	7.8	0.4643[1]
Swamp chestnut oak (3)	48.7	38.4 - 58.7	6.5	0.0301
Water oak (24)	16	0 - 42.2	15	0.4974
Nuttall oak (8)	64.3	21.0 - 92.6	10.2	<0.0001
Willow oak (11)	21.4	0 - 41.0	9.9	0.0918[1]

[1] p-value is derived from rank transformed data

Table 27 – Logistic regression (model 1) for survival of all bottomland study sites.

Species	n	Model Variables	Estimate	P-Value	Rescaled R^2
Cherrybark Oak	1132	Intercept	58.9564	0.0013	0.2857
		FOLR	0.0635	0.0001	
		Buffer pH	-7.0955	0.002	
		Potassium	-0.0135	<.0001	
		Organic Matter	-2.1345	0.0001	
Bur Oak	72	none significant			
Swamp Chestnut Oak	500	Intercept	3.9172	<.0001	0.4227
		Calcium	-0.00116	<.0001	
Water Oak	2583	Intercept	-9.003	<.0001	0.3713
		RCD	0.1464	<.0001	
		FOLR	0.064	0.0002	
		pH	1.5588	<.0001	
		Calcium	-0.00111	<.0001	
		Sulfur	0.2572	<.0001	
		Organic Matter	-0.7333	0.033	
Nuttall Oak	832	Intercept	-0.6067	0.2576	0.2577
		RCD	0.2256	<.0001	
		Potassium	-0.00908	<.0001	
		Manganese	0.0046	0.0104	
Willow Oak	2303	Intercept	2.2613	<.0001	0.5227
		FOLR	0.1006	0.0003	
		Zinc	0.3371	<.0001	
		CEC	-0.195	<.0001	
Shumard Oak	392	Intercept	-0.00834	0.9944	0.117
		RCD	0.2885	0.0015	
		Potassium	-0.0385	0.0134	

Table 28 - Logistic regression (model 2) for survival of the two flooded bottomland study sites (LH – CL and MI).

Species	n	Model Variables	Estimate	P-Value	Rescaled R^2
Cherrybark Oak	484	Intercept	1.152	0.0014	0.3567
		Flood Depth	-0.3034	<.0001	
		DTRF	0.0781	0.0038	
Bur Oak	72	none significant			
Swamp Chestnut Oak	227	Intercept	2.5934	0.001	0.0682
		Flood Depth	-0.3294	0.0008	
Water Oak	927	Intercept	-1.7347	0.0199	0.377
		Flood Depth	-0.3628	<.0001	
		RCD	0.1797	0.0001	
		Iron	0.00554	0.0009	
Nuttall Oak	580	Intercept	-0.0799	0.8772	0.1897
		RCD	0.209	<.0001	
		Potassium	-0.00915	<.0001	
Willow Oak	645	Intercept	6.0027	<.0001	0.4116
		Height	-0.0187	0.0037	
		FOLR	0.0779	0.0177	
		Organic Matter	-1.4124	0.0417	
		CEC	-0.1101	<.0001	
Shumard Oak	28	none significant			

Water oak survival had an R^2 of 37 percent. Significant model variables are presented here in decreasing order of importance: (RCD, soil calcium, soil pH, and soil sulfur), FOLR, and soil organic matter. Most variables were positively related to water oak survival, but soil calcium and organic matter were negatively related.

An R^2 of 26 percent was produced for Nuttall oak survival. Variables important to Nuttall oak survival were, in decreasing order of importance: RCD and soil potassium, and soil manganese. Soil potassium had the only negative relationship with Nuttall oak survival.

Willow oak survival had an R^2 of 52 percent. Important variables to willow oak survival are presented in decreasing order of importance: soil zinc and soil CEC, and FOLR. Independent variables had positive relationships except for soil CEC.

RCD and soil potassium, in decreasing order of importance, produced an R^2 of 12 percent for Shumard oak survival. Soil potassium had a negative relation with Shumard oak survival.

Model 2 (FWS Lower Hatchie NWR – Champion Lake and TWRA Moss Island WMA)

Flood depth and to a much lesser degree DTRF produced an R^2 of 36 percent for cherrybark oak survival. Increasing flood depth was associated with a decrease in the survival of cherrybark oak, but the opposite was true for DTRF.

Flood depth alone was significant with swamp chestnut oak survival with an R^2 of 7 percent. As flood depth increased, swamp chestnut oak survival decreased.

An R^2 of 38 percent was produced for water oak survival. Variables important to water oak survival are presented here in decreasing order of importance: flood depth, RCD, and soil iron. Root collar diameter and the soil iron concentration were positively related to water oak survival, but increasing flood depth was associated with water oak mortality.

RCD and soil potassium had an equally important relationship with Nuttall oak survival. The positively related RCD and negatively related soil potassium resulted in an R^2 of 19 percent for Nuttall oak survival.

Willow oak survival had an R^2 of 41 percent. Variables that were important to willow oak survival were, in decreasing order of importance: soil CEC, initial height, FOLR, and soil organic matter. FOLR had the only positive relationship to willow oak survival.

Differences Between Model 1 and Model 2

Model 2 for cherrybark oak produced a greater R^2 with flood depth as the most important independent variable. Flood depth was not available in the first model (model 1), but two of the most important independent variables for model 1 were strongly related to flood depth with an R-value greater than 0.7 (Table 4). FOLR also was important to cherrybark oak survival in the first model (model 1), but not model 2.

Flood depth was also important for swamp chestnut oak survival in model 2, but did not account for much of the variation in survival. Soil calcium, however, was very important to the survival of swamp chestnut oak in model 1 and produced a much higher R^2. Soil calcium was strongly correlated to flood depth with an r-value of 0.85 (Table 4).

The two models produced almost identical R^2 values for water oak survival. The most important variable in model 2 was flood depth, but RCD and soil iron were also important. Root collar diameter was very important in model 1 in addition to several soil parameters that are moderately to strongly related to flood depth with R-values ranging from 0.45 to 0.85 as well as FOLR (Table 4).

There was very little difference in the variables important to Nuttall oak survival between the two models. Root collar diameter and soil potassium were very important in both models, but soil manganese was also important in the first model (1) which had a higher rescaled R^2 value. Flood depth was not important to Nuttall oak survival.

Model 1 produced a higher R^2 value for willow oak survival than the second model (model 2) with FOLR, soil zinc, and soil CEC being important. In model 2, soil CEC was most important, but height, FOLR, and soil organic matter were also important. Willow oak survival was not significantly related to flood depth.

Bottomland Height Growth

Dieback occurred over all bottomland sites. Height growth averaged –16 cm, -14 cm, -52 cm, and –62 cm for WJ - S, WJ - N, LH - CL, and MI, respectively. Height growth differed between species at all sites (Table 29).

The WJ – S site had the second greatest height growth at –16 cm. Swamp chestnut oak and Nuttall oak had significantly greater height growth than all other species at –0.3 and –2.3 cm, respectively (Table 29). Shumard oak (-9.1 cm) and cherrybark oak (-11.7 cm) height growth did not differ, but they were less than swamp chestnut oak and Nuttall oak (Table 29). Willow oak (-14.6 cm) was less than Shumard oak and cherrybark oak, but greater than water oak (-25.3 cm) (Table 29). Only Nuttall oak and water oak had family height growth that differed (Table 30).

Table 29 – Height growth estimates for bottomland species by site.

Species	Wallace Johnston Tree Farm - Southern Field	Wallace Johnston Tree Farm - Northern Field	FWS Lower Hatchie NWR - Champion Lake[1]	TWRA Moss Island
Cherrybark oak	-11.7329 B[2]	-12.3171 B	-36.5929 A	-59.0094 A
Bur oak	NA	NA	NA	-53.7684 A
Swamp chestnut oak	-0.2959 A	-0.8636 A	NA	-56.7343 A
Water oak	-25.3156 D	-25.8355 C	-70.5941 C	-77.1115 B
Nuttall oak	-2.3436 A	NA	-41.9652 A	-49.0438 A
Willow oak	-14.6325 C	-11.2507 B	-59.5901 B	-75.0812 B
Shumard oak	-9.1108 B	-6.901 AB	-62.2665 ABC	NA
p-value	<0.0001	<0.0001	<0.0001	<0.0001
observations	3344	637	985	536

[1] p-value and mean separation derived from rank transformed data; estimates are derived from untransformed data
[2] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha=0.05 level.

Table 30 - ANOVA results comparing mean height growth among families with associated family mean and range for the Wallace Johnston Tree Farm – Southern Field.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Cherrybark oak (28)	-12	-48.9 - 0.8	7.7	0.2913
Swamp chestnut oak (4)	2.4	-1.5 - 5.8	2.1	0.1442
Water oak (44)	-25.7	-54.1 - -8.5	6	<0.0001
Nuttall oak (13)	-11.3	-47.3 - -1.4	5.6	0.0013
Willow oak (36)	-12.3	-45.0 - -4.7	3.5	0.218
Shumard oak (5)	-15.4	-25.2 - -10.8	4.8	0.1402

The WJ – N site had the greatest height growth of all bottomland sites at –14 cm. Swamp chestnut oak and Shumard oak height growth did not differ at –0.9 and –6.9 cm, respectively (Table 29). Cherrybark oak (-12.3 cm) and willow oak (-11.3 cm) were not different from each other or Shumard oak, but were less than swamp chestnut oak (Table 15). Water oak was less than all other species at –25.8 cm (Table 29). Shumard was the only species that had differences in family height growth (Table 31).

The LH – CL site had the third greatest height growth at –52 cm. Cherrybark oak, Nuttall oak, and Shumard oak height growth were not different at –36.6, -42, and –62.3 cm, respectively (Table 29). Willow oak (-59.6 cm) height growth did not differ from Shumard oak, but was less than cherrybark oak and Nuttall oak (Table 29). Nuttall oak was the only species with significant family differences in height growth (Table 32).

The MI site had the least amount of height growth at –62 cm. Nuttall oak (-49 cm), bur oak (-53.8 cm), swamp chestnut oak (-56.7 cm), and cherrybark oak (-59 cm) height growth did not differ (Table 29). Willow oak and water oak were not different at –75.1 and –77.1 cm, respectively, but they were less than other oak species mentioned above (Table 29). The only family differences occurred in Nuttall oak (Table 33).

Influences on Height Growth

Multiple linear regression models (1) produced R^2 values for species ranging from 0.12 to 0.60 and included all bottomland sites (Table 34). The second group of models (2) produced R^2 values for species that range from 0.04 to 0.60 and included only the flooded/submerged bottomland sites, LH – CL and MI (Table 35). The third group of dummy regression models (3) produced R^2 values for species that range from 0.30 to 0.57

Table 31 - - ANOVA results comparing mean height growth among families with associated family mean and range for the Wallace Johnston Tree Farm – Northern Field.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Cherrybark oak (9)	-12.4	-20.0 - -6.6	6.8	0.8214[1]
Swamp chestnut oak (4)	3.9	1.5 - 8.1	4.1	0.9784[1]
Water oak (15)	-29.3	-51.7 - -7.5	9.6	0.0795[1]
Willow oak (9)	-9.9	-15.5 - -4.8	3.8	0.0846
Shumard oak (5)	-14.7	-42.4 - 8.6	6.3	0.0009

[1] p-value is derived from rank transformed data

Table 32 - ANOVA results comparing mean height growth among families with associated family mean and range for the FWS Lower Hatchie NWR – Champion Lake.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Cherrybark oak (17)	-31.5	-68.0 - -5.2	13.3	0.2830[1]
Water oak (32)	-65	-88.9 - -18.9	13.5	0.4313[1]
Nuttall oak (10)	-41.6	-75.1 - -16.1	8.4	<0.0001[1]
Willow oak (18)	-62.3	-83.6 - -34.4	10	0.3368[1]
Shumard oak (2)	-69.5	-70.8 - -68.1	13.7	*

[1] p-value is derived from rank transformed data

* Infinite likelihood occurred

Table 33 - ANOVA results comparing mean height growth among families with associated family mean and range for the TWRA Moss Island WMA.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Cherrybark oak (13)	-63.5	-89.9 - -43.0	19	0.738
Bur oak (2)	-27	-27.2 - -26.8	5.5	0.9646
Swamp chestnut oak (3)	-52.2	-56.8 - -44.2	6.4	0.4184
Water oak (24)	-82.4	-94.9 - -57.5	10.4	0.4738
Nuttall oak (8)	-56.1	-91.7 - -28.5	10.3	0.0144
Willow oak (11)	-77.9	-97.2 - -54.5	10	0.1533

Table 34 – Multiple linear regression (model 1) for height growth of all bottomland study sites.

Species	n	Model Variables	Estimate	P-Value	Model R^2	Model P-Value
Cherrybark Oak	778	Intercept	19.43389	<.0001	0.1333	<.0001
		FOLR	0.53512	0.0126		
		Height	-0.53385	<.0001		
		Zinc	4.39607	<.0001		
Bur Oak	55	Intercept	-264.43558	<.0001	0.5959	<.0001
		Height	-0.57646	0.001		
		Organic Matter	166.09605	<.0001		
Swamp Chestnut Oak	361	Intercept	67.83967	<.0001	0.5922	<.0001
		Height	-0.35971	<.0001		
		FOLR	0.23331	0.0105		
		RCD	0.53991	0.0154		
		Copper	-18.13352	<.0001		
Water Oak	1614	Intercept	88.45706	<.0001	0.2283	<.0001
		Height	-0.67431	<.0001		
		Organic Matter	-48.34861	<.0001		
		FOLR	0.58426	0.0006		
		Deer Browse	18.86539	<.0001		
Nuttall Oak	684	Intercept	21.69433	<.0001	0.1343	<.0001
		Height	-0.33529	<.0001		
		Potassium	-0.18716	<.0001		
Willow Oak	1671	Intercept	53.33735	<.0001	0.3651	<.0001
		Height	-0.67198	<.0001		
		Organic Matter	-47.10937	<.0001		
		Sulfur	5.11321	<.0001		
Shumard Oak	337	Intercept	54.53133	<.0001	0.2489	<.0001
		Height	-0.55808	<.0001		
		RCD	3.02589	0.0002		
		Calcium	-0.07367	<.0001		

* P-values and r-squared values are derived from ranked data, and estimates are produced from untransformed data

Table 35 - Multiple linear regression (model 2) for height growth of the two flooded bottomland study sites (LH – CL and MI).

Species	n	Model Variables	Estimate	P-Value	Model R^2	Model P-Value
Cherrybark Oak	256	Intercept	37.69505	<.0001	0.247	<.0001
		Flood Depth	-6.19046	<.0001		
		Deer Browse	30.65723	0.0025		
		Height	-0.55968	0.001		
		FOLR	0.85602	0.028		
Bur Oak	55	Intercept	-264.43558	<.0001	0.5959	<.0001
		Height	-0.57646	0.001		
		Organic Matter	166.09605	<.0001		
Swamp Chestnut Oak	109	Intercept	-14.3546	<.0001	0.0385	0.0409
		Height	-0.36654	0.0409		
Water Oak	351	Intercept	57.34486	<.0001	0.4305	<.0001
		Height	-1.03068	<.0001		
		Flood Depth	-3.08305	<.0001		
		Deer Browse	98.40941	0.0006		
Nuttall Oak	444	Intercept	-10.52679	<.0001	0.0834	<.0001
		Height	-0.5108	<.0001		
		FOLR	0.7851	0.0201		
		Deer Browse	39.32096	0.0227		
		Phosphorous	0.37132	0.002		
Willow Oak	286	Intercept	148.46688	<.0001	0.3098	<.0001
		Height	-1.19904	<.0001		
		Organic Matter	-51.381686	<.0001		
		DTRF	-1.46011	0.0039		
Shumard Oak	18	none significant				

* P-values and r-squared values are derived from ranked data; estimates are produced from untransformed data

and included all bottomland sites with a class variable of submerging flood (Table 36). Slopes did not differ across the two flooded sites (LH – CL and MI) or the WJ –S and WJ – N sites, but slopes were different between all bottomland sites.

Model 1 (all bottomland sites)

An R^2 of 13 percent was produced for cherrybark oak height growth. Significant variables for cherrybark oak height growth are presented in decreasing order of importance: initial height and soil zinc, and FOLR. Initial height was the only variable with a negative relationship to height growth.

Soil organic matter and to a lesser degree initial height were important to bur oak height growth and produced an R^2 of 60 percent. Initial height had a negative relationship to height growth.

An R^2 of 59 percent was produced for swamp chestnut oak height growth. Variables in the model were, in decreasing order of importance: initial height and soil copper, FOLR, and RCD. Initial height and soil copper had a negative relationship with height growth.

The water oak model resulted in an R^2 of 23 percent for height growth. (Initial height, soil organic matter, and deer browse), and FOLR were significant variables for water oak height growth. Initial height and soil organic matter were both negatively related to water oak height growth.

Initial height and soil potassium were both equally important to Nuttall oak height growth and produced an R^2 of 13 percent. Both variables had a negative relationship with Nuttall oak height growth.

Table 36 – Dummy regression (model 3) for height growth of all bottomland study sites with submerging floods as the class variable. (class=0, then submerging flood was present; class=1, then submerging flood was not present)

Species	n	Model Variables	Class	Estimate	P-Value	Model R^2	Model P-Value
Cherrybark Oak	778	Flood	0	25.733001		0.3211	<.0001
		Flood	1	6.8412341			
		Copper		13.151913	0.0228		
		FOLR		0.6958157	0.0008		
		Height		-0.5357074	<.0001		
		Potassium		-0.3596637	<.0001		
		Deer Browse		7.5029858	0.0411		
Bur Oak	55	not on flooded and non-flooded sites					
Swamp Chestnut Oak	361	class variable not significant					
Water Oak	1614	Flood	0	46.777796		0.445	<.0001
		Flood	1	15.368009			
		Height		-0.6536145	<.0001		
		CEC		-1.0244278	<.0001		
		FOLR		0.6407774	0.0002		
		Deer Browse		10.14874	<.0001		
Nuttall Oak	684	Flood	0	35.140635		0.3018	<.0001
		Flood	1	-13.640259			
		Height		-0.4409406	<.0001		
		Phosphorous		0.3240188	0.0009		
		FOLR		0.516495	0.0315		
Willow Oak	1671	Flood	0	55.391716		0.5705	<.0001
		Flood	1	14.116104			
		Height		-0.5941095	<.0001		
		CEC		-4.6862907	0.0136		
		FOLR		0.6283402	0.0001		
		Calcium		0.0284089	0.0443		
Shumard Oak	337	Flood	0	24.139118		0.3008	<.0001
		Flood	1	-26.060564			
		Height		-0.5267143	<.0001		
		RCD		2.8223205	0.0006		
		DTRF		-0.6367637	0.0001		

An R^2 of 37 percent was produced for willow oak height growth. Initial height, soil organic matter, and soil sulfur were all equally important to willow oak height growth. Initial height and soil organic matter were negatively related to height growth.

The Shumard oak model produced an R^2 of 25 percent for height growth. Initial height and soil calcium were both equally important to height growth, followed by RCD. Initial height and soil calcium were negatively related to Shumard oak height growth.

Model 2 (FWS Lower Hatchie NWR – Champion Lake and TWRA Moss Island WMA)

An R^2 of 25 percent was produced for cherrybark oak height growth. Important variables for cherrybark oak height growth are, in decreasing order of importance: flood depth, initial height, deer browse, and FOLR. Flood depth and initial height were the only variables with a negative relation to height growth.

Organic matter and to a lesser extent initial height were significant to bur oak height growth and produced an R^2 of 60 percent. Initial height had a negative relationship with height growth.

An R^2 of only 4 percent was produced for swamp chestnut oak height growth. Initial height had a negative relationship and was the only variable significantly related to swamp chestnut oak height growth.

The water oak model resulted in an R^2 of 43 percent for height growth. Initial height and flood depth were most important to height growth followed by deer browse. Initial height and flood depth were negatively related to water oak height growth.

Nuttall oak height growth had an R^2 of 8 percent. Significant variables for Nuttall oak height growth included: initial height, soil phosphorous, FOLR, and deer browse, in decreasing order of importance. Initial height was the only variable with a negative relationship with height growth

An R^2 of 31 percent was produced for willow oak height growth. Initial height and soil organic matter were equally important to willow oak height growth, followed by DTRF. All variables were negatively related to height growth.

Model 3 (all bottomland sites with flooding as a class variable)

An R^2 of 32 percent was produced for cherrybark oak height growth. Significant variables, in decreasing order of importance, included: initial height and soil potassium, FOLR, soil copper, and deer browse. Initial height and soil potassium were the only variables that were negatively related to height growth.

The water oak model resulted in an R^2 of 45 percent for height growth. Initial height, soil CEC, and deer browse were all equally important to water oak height growth, followed in importance by FOLR. Initial height and soil CEC were the only variables negatively related to water oak height growth.

Nuttall oak height growth had an R^2 of 30 percent. Significant variables for height growth included: initial height, soil phosphorous, and FOLR, in decreasing order of importance. Initial height was the only variable with a negative relationship to height growth.

An R^2 of 57 percent was produced for willow oak height growth. The following variables in decreasing order of importance: initial height, FOLR, soil CEC, and soil calcium. Initial height and soil CEC were the only variables negatively related to height growth.

The Shumard oak model produced an r^2 of 30 percent for height growth. Initial height, DTRF, and RCD, in decreasing order of importance, were important to Shumard oak height growth. Initial height and RCD were negatively related to height growth.

Differences Between Model 1, Model 2, and Model 3

Initial height and soil zinc were the most important factors in model 1 for cherrybark oak height growth. When flood depth was incorporated into the second model (model 2), initial height became second in importance behind flood depth. With the presence or absence of submerging floods accounted for in model 3, initial height, soil potassium, and FOLR rose in importance and produced the greatest R^2 of all the models at 32 percent.

Model 1 produced an R^2 of 59 percent in which initial height and soil copper were most important to swamp chestnut oak height growth. The R^2 decreased to 4 percent for the second model (model 2) where initial height was the only variable. Flood depth was not significant in model 2 for swamp chestnut oak. Model 3 did not produce an R^2 for swamp chestnut oak because the flood class variable was not important.

Initial height, soil organic matter, and deer browse were very important to water oak height growth in model 1. With the inclusion of flood depth in the second model (model 2), initial height remained very important and was joined by flood depth. Model 3 produced the highest R^2 at 45 percent with submerging floods as the class variable and initial height, soil CEC, and deer browse were the most important independent variables.

In the first model (model 1), initial height and soil potassium were the most important variables to Nuttall oak height growth. Soil potassium was removed from the most important variables for model 2, but initial height remained as the most important independent variable. The third model (model 3) accounted for submerging floods and increased the R^2 to 30 percent with initial height remaining as the most important independent variable.

Initial height, soil organic matter, and soil sulfur were the most important variables in model 1 for willow oak height growth. The second model (model 2) removed soil sulfur from the variables used in model 1. The third model (model 3) produced the highest R^2 at 57 percent and kept initial height as the most important variable for willow oak height growth.

The most important variables for Shumard oak height growth in model 1 were initial height and soil calcium. None of the variables were significant in model 2 for Shumard oak. Initial height was the most important variable in model 3 for Shumard oak which also produced the highest R^2 of 30 percent.

For each model and species analyzed, initial height was an important variable with a negative relationship to height growth. Also, flood depth had a negative relationship to height growth every time it was present in a model. RCD and FOLR always exhibited a positive relation to height growth when present.

Split Plot Treatment Design

There were interactions between DTRF and height growth on the WJ-S site (Table 37). Water oak had less dieback in the 35-40 cm DTRF range than the 0-10 cm range. Nuttall oak had the greatest amount of dieback when DTRF was 20-25 cm.

Table 37 - Split plot of Wallace Johnston Tree Farm – Southern Field with depth to redoximorphic feature as the whole plot and species as the subplot (P=0.0023).

Species	DTRF range (cm)	Height Growth Estimate (cm)	
Cherrybark oak	0-5	-11.7661	A
	5-10	-11.4388	A
	10-15	-13.5849	A
	15-20	-6.341	A
	20-25	-21.5122	A
	25-30	-11.3361	A
	30-35	-28.23	A
	35-40	-6.7509	A
Swamp chestnut oak	0-5	-1.4944	A
	5-10	8.0023	A
	10-15	4.1243	A
	15-20	1.8927	A
	25-30	-1.8456	A
	35-40	-9.6484	A
Water oak	0-5	-25.3081	B
	5-10	-27.4043	B
	10-15	-24.6873	AB
	15-20	-22.1931	AB
	20-25	-23.9067	AB
	25-30	-19.8094	AB
	30-35	-27.5428	AB
	35-40	-17.1112	A
Nuttall oak	0-5	-2.9231	A
	5-10	-0.6302	A
	10-15	-0.01397	A
	15-20	4.7952	A
	20-25	-35.6862	B
	25-30	10.0635	A
	30-35	13.3738	A
	35-40	-1.3878	A
Willow oak	0-5	-14.1013	A
	5-10	-17.4702	A
	10-15	-13.6388	A
	15-20	-10.5391	A
	20-25	-19.2692	A
	25-30	-20.3879	AB
	30-35	-40.0897	B
	35-40	-9.6741	A
Shumard oak	0-5	-7.939	AB
	5-10	-6.7186	AB
	10-15	-5.4822	AB
	15-20	2.5299	A
	20-25	-26.789	BC
	25-30	-18.2445	ABC
	30-35	-17.2585	ABC
	35-40	-39.6969	BC

Willow oak had the greatest amount of dieback in the 30-35 cm DTRF range compared to DTRF of 0-25 and 35-40 cm. Shumard oak had the greatest amount of height growth when growing in soil with DTRF of 15-20 cm compared to those growing in soil with DTRF of 20-25 and 35-40 cm.

Bottomland Basal Sprouting

Basal sprouting occurred on 5, 0.47, 15, and 13 percent of seedlings on the WJ - S, WJ - N, LH - CL, and MI, respectively. Sprouting occurrence differed between species for all sites except WJ – N (Table 38).

The WJ - S site had a relatively low occurrence of basal sprouting at 5 percent. Water oak (9.9%), Shumard oak (6.3%), Nuttall oak (3.6%), and swamp chestnut oak (1.8%) sprouting occurrence did not differ. Cherrybark oak (2.6%) was not different from swamp chestnut oak or Nuttall oak, but was less than water oak and Shumard oak sprouting occurrence. Willow oak (2.1%) did not differ from swamp chestnut oak and cherrybark oak sprouting, but was less than Nuttall oak. Water oak and willow oak had significant family differences in the occurrence of sprouting (Table 39).

The WJ – N species did not differ in their sprouting occurrence and less than 1 percent of the seedlings experienced sprouting. Also, there were no significant family differences in sprouting (Table 40).

The LH – CL site had the highest occurrence of basal sprouting at 15 percent. Water oak seedlings sprouted most often at 31 percent, significantly greater than all other species. Willow oak (22%) and Shumard oak (10%) sprouting was not

Table 38 – Sprouting occurrence estimates for all bottomland species by site.

Species	Wallace Johnston Tree Farm - Southern Field[1]	Wallace Johnston Tree Farm - Northern Field[1]	FWS Lower Hatchie NWR - Champion Lake	TWRA Moss Island[1]
Cherrybark oak	2.55% BC[2]	0.07% A	-5.72% D	6.19% BC
Bur oak	NA	NA	NA	2.45% BC
Swamp chestnut oak	1.82% ABC	-0.13% A	NA	6.36% C
Water oak	9.90% A	1.17% A	31.10% A	27.21% A
Nuttall oak	3.56% AB	NA	12.55% C	11.08% C
Willow oak	2.13% C	0.06% A	21.91% B	18.61% AB
Shumard oak	6.29% A	1.32% A	9.84% BCD	NA
p-value	<0.0001	0.4583	<0.0001	<0.0001
observations	3344	637	985	536

[1] p-value and mean separation derived from rank transformed data; estimates are derived from untransformed data

[2] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha=0.05 level.

Table 39 – ANOVA results comparing mean basal sprouting occurrence among families with associated family mean and range for the Wallace Johnston Tree Farm – Southern Field.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Cherrybark oak (28)	1.8	0 - 12.7	6.2	0.4234[1]
Swamp chestnut oak (4)	NA	NA	NA	*
Water oak (44)	10.1	0 - 36.3	8.2	<0.0001[1]
Nuttall oak (13)	3.8	0 - 33.8	4.6	0.1960[1]
Willow oak (36)	2.3	0 - 9.4	3.4	0.0335[1]
Shumard oak (5)	4.9	2.6 - 6.8	3.3	0.5826[1]

[1] p-value is derived from rank transformed data

* Infinite likelihood occurred

Table 40 - ANOVA results comparing mean basal sprouting occurrence among families with associated family mean and range for the Wallace Johnston Tree Farm – Northern Field.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Cherrybark oak (9)	NA	NA	NA	*
Swamp chestnut oak (4)	NA	NA	NA	*
Water oak (15)	1.3	0 - 12.1	3.8	0.0944[1]
Willow oak (9)	NA	NA	NA	*
Shumard oak (5)	NA	NA	NA	*

[1] p-value is derived from rank transformed data

* Infinite likelihood occurred

significantly different. Nuttall oak (13%) sprouting was not significantly different than Shumard oak, but was significantly less than willow oak. Cherrybark oak sprouting was estimated at –6% which was not significantly different than Shumard oak, but was significantly less than Nuttall oak. There were only significant family differences in willow oak basal sprouting (Table 41).

Thirteen percent of the seedlings on the MI site had basal sprouting. Water oak (27%) and willow oak (19%) sprouting did not differ. Cherrybark oak (6%) and bur oak (2%) did not differ from willow oak, but were significantly less than water oak. Swamp chestnut oak (6%) and Nuttall oak (11%) were not different from cherrybark oak and bur oak, but were less than willow oak. There were no significant family differences for sprouting at MI (Table 42).

Influences on Basal Sprouting

Logistic regression models (1) produced rescaled R^2 values of less than 0.01 for species and included all bottomland sites. The second group of logistic regression models (2) produced rescaled R^2 values for species that ranged from 0.13 to 0.35 and included only the LH – CL and MI sites (Table 43). The first model (1) is not presented due negligible rescaled R^2 values. Nuttall oak slopes did not differ across the second model (2) sites, but water oak slopes were marginally significant at $p=0.0495$. Only swamp chestnut oak, water oak, and Nuttall oak had independent variables related to the occurrence of basal sprouting (Table 43).

An R^2 of 35 percent was produced for swamp chestnut oak sprouting. Flood depth was the only significant variable and was positively associated with sprouting.

Table 41 - ANOVA results comparing mean basal sprouting occurrence among families with associated family mean and range for FWS Lower Hatchie NWR – Champion Lake.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Cherrybark oak (17)	6	0 - 31.1	10	0.0786[1]
Water oak (32)	45.9	10.2 - 91.1	23.3	0.08081[1]
Nuttall oak (10)	2.7	0 - 7.7	4	0.1063[1]
Willow oak (18)	12.4	0 - 30.5	10.6	0.0243[1]
Shumard oak (2)	NA	NA	NA	*

[1] p-value is derived from rank transformed data

* Infinite likelihood occurred

Table 42 - ANOVA results comparing mean basal sprouting occurrence among families with associated family mean and range for TWRA Moss Island WMA.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Cherrybark oak (13)	8.7	0 - 50	13.3	0.5048[1]
Bur oak (2)	NA	NA	NA	*
Swamp chestnut oak (3)	6.8	4.8 - 9.6	4.4	0.6358[1]
Water oak (24)	27.6	2.2 - 63.9	19	0.0954[1]
Nuttall oak (8)	16.3	0 - 50	9.2	0.1628[1]
Willow oak (11)	17.6	0 - 33.3	15.2	0.3427[1]

[1] p-value is derived from rank transformed data

* Infinite likelihood occurred

Table 43 - Logistic regression (2) for sprouting on the two flooded bottomland study sites (FWS Lower Hatchie NWR – Champion Lake and TWRA Moss Island WMA).

Species	n	Model Variables	Estimate	P-Value	Rescaled R^2
Cherrybark Oak	256	none significant			
Bur Oak	55	none significant			
Swamp Chestnut Oak	109	Intercept	-12.1015	<.0001	0.3481
		Flood Depth	1.122	0.0006	
Water Oak	927	Intercept	-2.8039	0.0009	0.1989
		Flood Depth	-0.7227	<.0001	
		Magnesium	0.00341	0.006	
		Organic Matter	2.7465	0.0008	
Nuttall Oak	580	Intercept	-9.6233	<.0001	0.1337
		Flood Depth	-0.3267	0.0296	
		Height	0.0281	0.0207	
		Copper	1.4208	0.0004	
Willow Oak	645	none significant			
Shumard Oak	28	none significant			

Flood depth, soil organic matter, and soil magnesium were important to water oak sprouting, in decreasing order of importance. These variables combined to produced an R^2 of 20 percent. Flood depth was the only variable that was negatively related to sprouting.

An R^2 of 13 percent was produced by soil copper, initial height, and flood depth for Nuttall oak basal sprouting, in decreasing order of importance. As flood depth increased, sprouting decreased with Nuttall oak, but the other variables were positively related.

Upland Planting Stock

There were differences in initial seedling measurements across study sites for the majority of the seedlings (Table 44). Table 45 shows that initial seedling measurements differed between species at each site, except PE where only northern red oak occurred. In addition to species differences, significant family differences were observed in most of the initial seedling measurements (Table 46-54).

Correlation values of seedling measurements ranged between 0.12 and 0.75 across all species (Table 55). The correlation between FOLR and RCD was the strongest for southern red oak. The FOLR – height relationship was not the strongest relationship for any species, and the RCD – height correlation was strongest for black walnut (only correlation calculated), white oak (only correlation calculated), pin oak, northern red oak, and black oak.

Planting stock means were above sample means for all parameters measured except for white oak height (Table 56 and 57). The AC site had 23, 10, and 13 percent

Table 44 - Mean initial height, mean initial root collar diameter, and mean number of initial first order lateral roots of planting stock for the upland studies.

	Species (observations)	Strawberry Plains Audubon Center	FWS Lower Hatchie NWR - Upland Site	Pat Estes Tree Farm	P-Value
Initial Height (cm)	Black walnut (132)	99.21 B[1]	119.33 A	NA	<0.0001
	White oak (194)	66.5 A	64.42 A	NA	0.4295
	Southern red oak (329)	92.93 B	111.32 A	NA	<0.0001
	Pin oak (308)	109.19 B	115.94 A	NA	0.0016
	Northern red oak (299)	NA	NA	130.3	NA
	Black oak (322)	88.11 B	93.02 A	NA	0.0183
Initial Root Collar Diameter (mm)	Black walnut (132)	14.3 B	15.98 A	NA	0.0022
	White oak (194)	11.12 A	11.35 A	NA	0.5066
	Southern red oak (329)	10.53 A	10.53 A	NA	0.9913
	Pin oak (308)	13.16 A	12.83 A	NA	0.2014
	Northern red oak (299)	NA	NA	12.77	NA
	Black oak (322)	12.12 A	11.61 B	NA	0.0463
# Initial First Order Lateral Roots	Black walnut (132)	NA	NA	NA	NA
	White oak (194)	NA	NA	NA	NA
	Southern red oak (329)	9.19 B	11.18 A	NA	0.0004
	Pin oak (308)	11.85 A	12.01 A	NA	0.7323
	Northern red oak (299)	NA	NA	12.79	NA
	Black oak (322)	NA	NA	NA	NA

[1] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha=0.05 level.

Table 45 – Species differences in mean initial height, mean initial root collar diameter, and mean number of initial first order lateral roots of planting stock for the upland studies.

	Species (observations)	Initial Height(cm)	Initial RCD(mm)	Initial FOLR
Strawberry Plains Audubon Center	Black walnut	99.2099 B	14.2975 A	NA
	White oak	66.5031 E	11.1229 D	NA
	Southern red oak	92.9348 C	10.5293 E	9.1902 C
	Pin oak	109.19 A	12.8347 B	11.8466 A
	Black oak	88.1136 D	12.1227 C	10.5284 B
	p-value	<0.0001	<0.0001	<0.0001
	n	771	771	536
FWS Lower Hatchie NWR - Upland Site	Black walnut	119.33 A	15.9769 A	NA
	White oak	64.4194 D	11.3548 CD	NA
	Southern red oak	111.32 B	10.5313 D	11.1769 AB
	Pin oak	115.94 A	13.1636 B	12.0076 A
	Black oak	93.0205 C	11.6068 C	10.6164 B
	p-value	<0.0001	<0.0001	0.0445
	n	505	505	425
Pat Estes Tree Farm	Northern red oak	130.3	12.77	12.79
	p-value	NA	NA	NA
	n	299	299	299

[1] Mean separation by Fisher's protected least significant difference tests (LSD). Means within a site and column followed by the same letter are not significantly different at the alpha=0.05 level.

Table 46 - ANOVA results comparing mean initial height among families with associated family mean and range for Strawberry Plains Audubon Center.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Black walnut (5)	84.9	27.0 - 111.7	6.4	<0.0001
White oak (11)	66.4	59.1 - 82.8	3.6	<0.0001
Southern red oak (4)	92.5	79.7 - 124.1	2.3	<0.0001
Pin oak (4)	109.1	100.7 - 114.4	3	0.0074
Black oak (4)	82.7	60.0 - 99.6	2.6	<0.0001

Table 47 - ANOVA results comparing mean initial root collar diameter among families with associated family mean and range for Strawberry Plains Audubon Center.

Species (# families)	Family Mean (mm)	Family Range (mm)	Mean SE	Family P-Value
Black walnut (5)	13.5	10.1 - 15.9	1	0.0007
White oak (11)	11.1	10.3 - 12.7	0.5	<0.0001
Southern red oak (4)	10.5	9.8 - 11.3	0.2	<0.0001
Pin oak (4)	12.8	11.3 - 14.7	0.3	<0.0001
Black oak (4)	11.9	10.9 - 12.4	0.4	0.0186

Table 48 - ANOVA results comparing mean initial first order lateral roots among families with associated family mean and range for Strawberry Plains Audubon Center.

Species (# families)	Family Mean (mm)	Family Range (mm)	Mean SE	Family P-Value
Black walnut (5)	NA	NA	NA	NA
White oak (11)	NA	NA	NA	NA
Southern red oak (4)	9.1	6.5 - 12.5	0.6	<0.0001
Pin oak (4)	11.9	8.7 - 13.7	0.6	<0.0001
Black oak (4)	9.9	7.8 - 11.9	0.7	0.0003

Table 49 - ANOVA results comparing mean initial height among families with associated family mean and range for FWS Lower Hatchie NWR - Upland.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Black walnut (4)	111.9	87.0 - 128.4	6	0.0011
White oak (9)	65.1	51.5 - 89.5	7	0.0099
Southern red oak (4)	111.2	99.3 - 126.9	2.1	<0.0001
Pin oak (4)	115.8	106.6 - 122.5	2.6	0.0001
Black oak (5)	88.2	69.0 - 101.8	5	<0.0001

Table 50 - ANOVA results comparing mean initial root collar diameter among families with associated family mean and range for FWS Lower Hatchie NWR - Upland.

Species (# families)	Family Mean (mm)	Family Range (mm)	Mean SE	Family P-Value
Black walnut (4)	15.3	13.7 - 17.6	1.2	0.0066
White oak (9)	11.4	9.8 - 14.0	1.2	0.1249
Southern red oak (4)	10.5	9.8 - 11.1	0.3	0.0005
Pin oak (4)	13.2	12.4 - 14.1	0.4	0.0071
Black oak (5)	11.7	10.0 - 12.9	0.7	<0.0001

Table 51 - ANOVA results comparing mean initial first order lateral roots among families with associated family mean and range for FWS Lower Hatchie NWR - Upland.

Species (# families)	Family Mean (mm)	Family Range (mm)	Mean SE	Family P-Value
Black walnut (4)	NA	NA	NA	NA
White oak (9)	NA	NA	NA	NA
Southern red oak (4)	11.2	7.3 - 14.5	0.8	<0.0001
Pin oak (4)	12	9.7 - 13.5	0.6	0.0004
Black oak (5)	10.2	8.0 - 12.2	1.4	0.0542

Table 52 - ANOVA results comparing mean initial height among families with associated family mean and range for Pat Estes Tree Farm.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Northern red oak (20)	128.3	65.0 - 150.3	7.5	<0.0001

Table 53 - ANOVA results comparing mean initial root collar diameter among families with associated family mean and range for Pat Estes Tree Farm.

Species (# families)	Family Mean (mm)	Family Range (mm)	Mean SE	Family P-Value
Northern red oak (20)	12.7	9.2 - 14.9	0.6	<0.0001

Table 54 - ANOVA results comparing mean initial first order lateral roots among families with associated family mean and range for Pat Estes Tree Farm.

Species (# families)	Family Mean (mm)	Family Range (mm)	Mean SE	Family P-Value
Northern red oak (20)	14	5.6 - 20.7	1.5	<0.0001

Table 55 – Pearson correlation coefficients for initial seedling measurements on upland study sites.

	FOLR-RCD	FOLR-Height	Height-RCD
Black walnut	NM	NM	0.71
White oak	NM	NM	0.12
Southern red oak	0.58	0.49	0.57
Pin oak	0.59	0.5	0.65
Northern red oak	0.62	0.52	0.72
Black oak	0.61	0.57	0.75

All correlation values are significant at alpha=0.05

NM - not measured

Table 56 – Comparison of planted and lifted seedlings to indicate relative planting stock quality for Strawberry Plains Audubon Center and FWS Lower Hatchie NWR – Upland.

Site	Seedling Measurement	Species	.... Planted .... Mean	n	.... Lifted .... Mean	n	Planted vs. Lifted (% difference)
Strawberry Plains Audubon Center	Initial Height (cm)	black walnut	99.21	81	59.37	301	67.10
		white oak	66.5	163	68.06	560	-2.29
		southern red oak	92.94	184	81.1	786	14.60
		pin oak	109.19	176	98.6	584	10.74
		black oak	88.11	176	69.42	652	26.92
							Mean Difference = 23.4%
	Initial Root Collar Diameter (mm)	black walnut	14.3	81	11.9	301	20.17
		white oak	11.12	163	10.97	560	1.37
		southern red oak	10.53	184	9.42	786	11.78
		pin oak	12.83	176	12.19	584	5.25
		black oak	12.12	176	10.74	652	12.85
							Mean Difference = 10.3%
	Number of Initial First Order Lateral Roots	black walnut	NA	81	NA	301	NA
		white oak	NA	163	NA	560	NA
		southern red oak	9.19	184	8.24	786	11.53
		pin oak	11.85	176	10.84	584	9.32
		black oak	10.53	176	8.85	652	18.98
							Mean Difference = 13.3%
			Overall Mean Difference = 15.7%				
FWS Lower Hatchie NWR - Upland Site	Initial Height (cm)	black walnut	119.33	52	73.12	369	63.20
		white oak	64.42	31	66.93	532	-3.75
		southern red oak	111.32	147	95.1	706	17.06
		pin oak	115.94	132	98.09	351	18.20
		black oak	93.02	146	69.43	853	33.98
							Mean Difference = 25.7%
	Initial Root Collar Diameter (mm)	black walnut	15.98	52	13.1	369	21.98
		white oak	11.35	31	11.11	532	2.16
		southern red oak	10.53	147	9.29	706	13.35
		pin oak	13.16	132	12.3	351	6.99
		black oak	11.61	146	10.49	853	10.68
							Mean Difference = 11%
	Number of Initial First Order Lateral Roots	black walnut	NA	52	NA	369	NA
		white oak	NA	31	NA	532	NA
		southern red oak	11.18	147	9.3	706	20.22
		pin oak	12.01	132	10.98	351	9.38
		black oak	10.62	146	9.12	853	16.45
							Mean Difference = 15.4%
			Overall Mean Difference = 17.4%				

Table 57 - Comparison of planted and lifted seedlings to indicate relative planting stock quality for Pat Estes Tree Farm.

	Seedling Measurement	Species	.... Planted .... Mean	n	.... Lifted .... Mean	n	Planted vs. Lifted (% difference)
Pat Estes Tree Farm	Initial height (cm)	northern red oak	12.77	300	9.97	2729	28.10
	Initial Root Collar Diameter (mm)	northern red oak	130.3	300	87.98	2729	48.10
	Number of Initial First Order Lateral Roots	northern red oak	12.79	300	9.86	2729	29.70
	Overall Mean Difference= 35.3%						

greater height, RCD, and FOLR, respectively, than sample means. LH – UP height, RCD, and FOLR were 26, 11, and 15 percent, respectively, greater than sample means. The PE site had 28, 48, and 30 percent higher measurements for height, RCD, and FOLR, respectively, than sample means.

Upland Survival

Seedling survival was 97, 93, and 90 percent for AC, LH -UP, and PE, respectively. Survival was different between species for all sites except the PE site where only one species was planted (Table 58).

The AC site had the highest survival at 97 percent. Black oak (100%), southern red oak (98%), and black walnut (96%) survival did not differ. Pin oak (94%) survival was not significantly different than black walnut, but was less than black oak and southern red oak. Black walnut and southern red oak had family survival differences (Table 59).

The LH - UP site had the second best survival at 93 percent. Pin oak survival (98%) was greater than all other species. Southern red oak (92%), black oak (90%), and black walnut (90%) survival did not differ. Southern red oak and black oak had significant family differences in survival (Table 60). The PE site did not have significant family differences for northern red oak survival (Table 61).

Influences on Survival

Analysis of logistic regression models produced rescaled R^2 values ranging from 0.11 to 0.52 (Table 62). Several slopes were significantly different between AC and LH – UP sites.

Table 58 – Survival estimates for the three upland study sites.

Species	Strawberry Plains Audubon Center[1]	FWS Lower Hatchie NWR - Upland Site[1]	Pat Estes Tree Farm[1]
Black walnut	96.06% AB[2]	89.88% B	NA
White oak	NA	NA	NA
Southern red oak	98.04% A	91.78% B	NA
Pin oak	94.23% B	98.34% A	NA
Northern red oak	NA	NA	91.24%
Black oak	99.97% A	90.25% B	NA
p-value	0.0106	0.007	NA
observations	617	474	299

[1] p-value and mean separation derived from rank transformed data; estimates are derived from untransformed data

[2] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha=0.05 level.

Table 59 – ANOVA results comparing mean survival among families with associated family mean and range for Strawberry Plains Audubon Center.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Black walnut (5)	87	46.0 - 100	4.7	<0.0001
Southern red oak (4)	97.4	85.0 - 100	2.7	<0.0001[1]
Pin oak (4)	96.5	92.5 - 98.7	2.7	0.2066[1]
Black oak (4)	98.3	97.0 - 99.7	2.4	0.8739[1]

[1] p-value is derived from rank transformed data

Table 60 - ANOVA results comparing mean survival among families with associated family mean and range for FWS Lower Hatchie NWR - Upland.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Black walnut (4)	94.1	88.8 - 100	13	0.709[1]
Southern red oak (4)	91.7	78.9 - 100	4.9	0.0457[1]
Pin oak (4)	99.2	97.0 - 100	1.6	0.4003[1]
Black oak (5)	75.7	18.4 - 96.2	10.8	0.0395[1]

[1] p-value is derived from rank transformed data

Table 61 - ANOVA results comparing mean survival among families with associated family mean and range for Pat Estes Tree Farm.

Species (# families)	Family Mean (%)	Family Range (%)	Mean SE	Family P-Value
Northern red oak (20)	91.2	63.1 - 100	10	0.20391

Table 62 – Logistic regression for survival of upland study sites

Species	n	Model Variables	Estimate	P-Value	Rescaled R^2
Black walnut	132	Intercept	600.8	0.0077	0.5181
		Buffer pH	-79.1122	0.0073	
		RCD	0.5875	0.0073	
		HT	0.0721	0.0051	
Southern red oak	329	Intercept	-0.7964	0.4376	0.1297
		Potassium	0.0233	0.0075	
		FOLR	0.1595	0.0177	
Pin oak	308	Intercept	-1.1464	0.5031	0.1122
		Height	0.0473	0.0068	
Northern red oak	294	none significant			
Black oak	322	Intercept	9.7543	<.0001	0.1104
		Sodium	-0.8046	0.0009	

An R^2 of 52 percent was produced for black walnut survival. The significant variables are presented in decreasing order of importance: buffer pH and RCD, and initial height. Buffer pH had the only negative relationship with black walnut survival.

Soil potassium and FOLR, in decreasing order of importance, combined to produce an R^2 of 13 percent for southern red oak survival. Both variables had a positive relationship with survival.

Initial height was important to pin oak survival and produced an R^2 value of 11 percent. Initial height was positively related to pin oak survival. There were no variables that were significantly related to northern red oak survival.

Soil sodium produced an R^2 of 11 percent for black oak survival. The relationship between soil sodium and black oak survival was negative.

Upland Height Growth

Height growth averaged 1.5, 6.2, and –16.8 cm for AC, LH – UP, and PE, respectively. Height growth differed significantly between species at the AC site, but not at the LH - UP site (Table 63).

Black oak (4.7 cm), pin oak (3.2 cm), and southern red oak (2.6 cm) height growth was not significantly different on the AC site. Black walnut height growth, at –11.1 cm, was significantly less than the other species. No families were significantly different on this site (Table 64).

Black oak (9.1 cm), pin oak (5.7 cm), southern red oak (5.2 cm), and black walnut (1.7 cm) height growth was not significantly different on the LH – UP site. Families

Table 63 – Height growth estimates for species by site for the upland studies.

Species	Strawberry Plains Audubon Center	FWS Lower Hatchie NWR - Upland Site	Pat Estes Tree Farm
Black walnut	-11.0926 B[1]	1.7074 B	NA
White oak	NA	NA	NA
Southern red oak	2.618 A	5.2037 AB	NA
Pin oak	3.1888 A	5.7278 AB	NA
Northern red oak	NA	NA	-16.84
Black oak	4.7077 A	9.143 A	NA
p-value	<0.0001	0.1569	NA
observations	561	422	258

[1] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha=0.05 level.
[*] Shaded area represents non-signficance even though the LSD mean separation indicates differences, the p-value is >0.05.

Table 64 – ANOVA results comparing mean height growth among families with associated family mean and range for Strawberry Plains Audubon Center.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Black walnut (5)	-10	-12.2 - -7.5	4.1	0.8144
Southern red oak (4)	1.9	0.35 - 3.6	1.6	0.5093
Pin oak (4)	1.2	-3.9 - 3.2	2.6	0.1855
Black oak (4)	6.6	3.1 - 9.3	2.3	0.1462

were significantly different in black oak on this site (Table 65). The northern red oak on the PE site had 17 cm of dieback and significant family differences (Table 66).

Influences on Height Growth

Multiple linear regression models for upland height growth produced R^2 values for species ranging from 3 to 11 percent (Table 67). Slopes were not significantly different across sites.

No variables were related to black walnut height growth. Initial height, however, was important in a negative relationship to southern red oak height growth, but only produced an R^2 of 3 percent.

Initial height, soil boron, and FOLR, in decreasing order of importance, produced an R^2 of 9 percent for pin oak height growth. Initial height was the only negative variable in the model.

Initial height and to a lesser degree, RCD, produced an R^2 of 8 percent for northern red oak height growth. Initial height was negatively related to northern red oak height growth.

Initial height, soil CEC, and RCD, in decreasing order of importance, were significant in relation to black oak height growth and produced an R^2 of 11 percent. Height and soil CEC were negatively related to black oak height growth.

Table 65 – ANOVA results comparing mean height growth among families with associated family mean and range for FWS Lower Hatchie NWR - Upland.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Black walnut (4)	2.2	-6.1 - 8.3	7.3	0.0683
Southern red oak (4)	5.2	-0.2 - 9.3	3.4	0.4993[1]
Pin oak (4)	5.9	-0.8 - 11.0	4.2	0.109
Black oak (5)	9.9	5.0 - 18.6	3.5	0.0343

[1] p-value is derived from rank transformed data

Table 66 – ANOVA results comparing mean height growth among families with associated family mean and range for the Pat Estes Tree Farm.

Species (# families)	Family Mean (cm)	Family Range (cm)	Mean SE	Family P-Value
Northern red oak (20)	-20.1	-40.5 - -0.4	9.1	0.0007

Table 67 – Multiple linear regression for height growth of all three upland sites.

Species	n	Model Variables	Estimate	P-Value	Model R^2	Model P-Value
Black walnut	121	none significant				
Southern red oak	310	Intercept	14.04237	0.0003	0.0254	0.0049
		Height	-0.10405	0.0049		
Pin oak	289	Intercept	-6.86758	0.5721	0.0873	<0.0001
		Height	-0.2871	<.0001		
		FOLR	0.6574	0.0196		
		Boron	46.71873	0.0018		
Northern red oak	258	Intercept	-1.3487	0.9067	0.081	<0.0001
		Height	-0.34132	<.0001		
		RCD	2.29997	0.0127		
Black oak	263	Intercept	52.71203	<.0001	0.1137	<0.0001
		Height	-0.25609	<.0001		
		RCD	0.92956	0.0301		
		CEC	-5.21669	0.0049		

Herbivory

Bottomland Sites

The only herbivory observed on the bottomland study sites was deer browse. Harvest mice (*Micromys minutus*) were observed on several of the sites, although they did not appear to be the source of any damage. Deer browse occurred on 10, 2, 1, and 1 percent of seedlings on WJ - S, WJ - N, LH - CL, and MI, respectively.

Deer browse was negligible, as determined by the author, for all bottomland sites, except WJ – S. Deer browse did not differ among species on the WJ – S site, but ranged from 5 to 11 percent for each species. Water oak, willow oak, and Shumard oak were the only species on the WJ – S site that had significant variables related to deer browse (Table 68). FOLR had a positive relationship and was important to water oak deer browse, but only produced an R^2 of 2 percent. Soil zinc was positively related to willow oak deer browse and was important in producing an R^2 of 4 percent. Height had a negative relationship with Shumard oak deer browse and produced an R^2 of 4 percent. Deer browse occurred on seedlings at the WJ – S site ranging from 53 to 170 cm in height.

Upland Sites

Deer browse occurred on 8, 27, and 3 percent of seedlings on the AC, LH – UP, and PE sites. The AC and LH - UP were the only sites that had deer browse of any appreciable amount, as determined by the author, and therefore these two sites were analyzed.

Table 68 – Logistic regression for deer browse on Wallace Johnston Tree Farm – Southern Field.

Species	n	Model Variables	Estimate	P-Value	Rescaled R^2
Cherrybark Oak	527	none significant			
Swamp Chestnut Oak	189	none significant			
Water Oak	1383	Intercept	-2.6992	<.0001	0.0205
		GradeFOLR	0.089	0.0002	
Nuttall Oak	252	none significant			
Willow Oak	1406	Intercept	-6.5701	<.0001	0.035
		Zn	0.9309	<.0001	
Shumard Oak	289	Intercept	0.176	0.8649	0.0433
		GradeHT	-0.02	0.0157	

Deer browse differed between species for both sites (Figure 8). Pin oak (12%), black oak (10%), and southern red oak (7%) deer browse were not significantly different on the AC site. Black walnut (1%) deer browse, however, was less than the oak species. On the LH – CL site, Black walnut (34%), pin oak (30%), and southern red oak (27%) deer browse was not different. The black walnut (2%) deer browse was significantly less than the oak species.

An R^2 of 17 percent was produced by a model that included the only variable important to black walnut deer browse, RCD, with a positive relationship (Table 69). The southern red oak deer browse model produced an R^2 of 19 percent with a positive relationship to soil calcium. The pin oak model included soil calcium, soil magnesium, and soil organic matter, in decreasing order of importance. The rescaled R^2 produced was 20 percent and soil calcium had the only positive relationship with pin oak deer browse. Significant variables for black oak deer browse were: soil calcium, initial height, and FOLR, in decreasing order of importance. These variables combined to produce a an R^2 of 31 percent with height having the only negative relationship.

Groundcovers and Competition

Browntop millet on the WJ – S and WJ – N sites was the only groundcover that germinated well and was the principal vegetation present in the tree rows by the end of the year. The browntop millet on the LH - CL and MI sites germinated well, but did not survive the flood events. The subsequent Japanese millet had poor germination and none of the plants were taller than a few inches at the MI site. Shortly after the flood event,

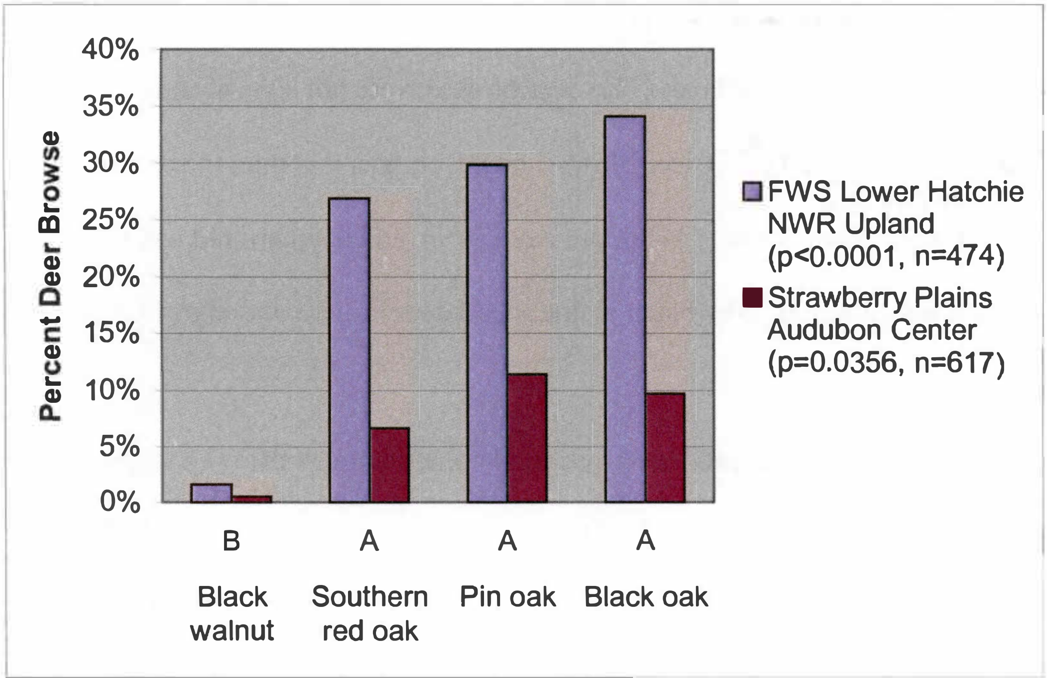

Figure 8 – Percent deer browse at two upland sites (Strawberry Plains Audubon Center and FWS Lower Hatchie NWR – Upland). Values followed by the same letter are not different at the alpha 0.05 level. (LSD)

Table 69 – Logistic regression for deer browse on two upland sites (Strawberry Plains Audubon Center and FWS Lower Hatchie NWR - Upland).

Species	n	Model Variables	Estimate	P-Value	Rescaled R^2
Black walnut	132	Intercept	-10.1946	0.004	0.1682
		GradeRCD	0.3846	0.0421	
Southern red oak	329	Intercept	-6.2097	<.0001	0.1927
		Ca	0.00718	<.0001	
Pin oak	308	Intercept	7.24	0.0844	0.2023
		Ca	0.0142	0.0004	
		Mg	-0.0652	0.011	
		OM	-10.9893	0.0174	
Black oak	322	Intercept	-5.8598	<.0001	0.312
		Ca	0.0091	<.0001	
		GradeHT	-0.0225	0.0142	
		GradeFOLR	0.082	0.0367	

both sites were colonized with volunteer weeds, grasses, and forbes, e.g. cockleburs (*Xanthium* L.). On both sites, the higher elevations had herbaceous vegetation that often overtopped or nearly overtopped the seedlings while the lower elevations contained mainly lower vegetation that rarely overtopped the seedlings. Vines were not a problem on any bottomland sites.

Browntop millet on two upland sites, AC and LH - UP, had poor germination and did not survive the year. The yellow sweetclover on these two sites had good germination, but was quickly out-competed by competition. Herbaceous vegetation also quickly replaced the winter wheat when it began to thin out in June. These sites contained weeds, grasses, and forbs by the end of the year that often overtopped the seedlings and negated groundcover treatments.

Crop Production

The WJ – S site produced approximately 300 bushels of soybeans. The LH – CL and LH – UP sites produced approximately 175 and 85 bushels, respectively. Average yields for the WJ – S, LH – CL, and LH – UP sites in previous years were 875, 300, and 150 bushels, respectively. The average yield prior to alley cropping was 30 bushels per acre and 25 bushels per acre with alley cropping. The sunflower/millet crop on the AC site was not harvested for production.

Economics

Tree Establishment

Planting stock cost was $0.65 per seedling, assuming a 40 percent cull rate, and at approximately 160 seedlings per acre results in $104 per acre. Design layout and species locations, without experimental design layout, was $10 per acre. Groundcover seed for tree rows, browntop millet, was $18 per acre. Tree row tillage and groundcover planting was $20 per acre. Tree planting, without an experimental design, was $60 per acre with augers. Machine planting was estimated to cost $100 to $130 per acre for these large seedlings (Mercker, 2004). This results in total tree establishment costs of $212 per acre for auger planting, and $252-$282 per acre for machine planting.

Crop Production

Tillage, planting, and seed costs were a total of $45 per acre of soybeans. Glyphosate was $17.50 per acre, applied. Harvesting costs were $25 per acre. Soybean production prior to alley cropping and with alley cropping was approximately 30 and 25 bushels per acre, respectively. Prices averaged $5.71 (5 year average) per bushel for $171.30 per acre of gross profit prior to alley cropping and $142.75 with alley cropping. The net profit was $83.80 per acre for soybean production prior to alley cropping and $55.25 per acre with alley cropping.

Profit/Loss

Soybeans were planted on approximately 60 percent of the acreage in the alley cropping designs, and the seedlings and groundcover occupied the remaining 40 percent. The net loss, compared to full soybean production, for the establishment year of alley cropping these sites was -$51.65 per acre for auger planted seedlings and -$67.65 to -$79.65 per acre for machine planted seedlings.

CHAPTER V.

DISCUSSION

Seedling Quality

Seedling quality, as defined by height, RCD, and FOLR, has been cited as a critical factor in outplanted survival and growth (Hodges and Janzen, 1986; Kormanik et al., 1995). Studies have suggested that only 40 to 60 percent of nursery seedlings are acceptable planting stock (Kormanik and Ruehle, 1986; Kormanik et al., 1989). Planted seedling quality in this study was 4 to 55 percent greater than the sample mean for all bottomland studies (Table 20 and 21), and 10 to 48 percent higher than the sample mean for upland studies (Table 56 and 57), indicating that the planted seedlings were of acceptable quality.

The seedlings were visually selected for quality. Pearson correlation analyses showed that there was no single correlation, e.g. FOLR-RCD, that represented the highest R-value for all species in bottomland plantings (Table 19). As any single characteristic increased in value, there was a concurrent increase in other characteristics. Therefore using a combination of visually assessed characteristics, rather than any one specific characteristic, is effective in selecting the highest quality seedlings. The upland plantings, however, show that the height-RCD correlation was generally the strongest relationship, although characteristics still increased in value in concert (Table 55). Visually assessing one characteristic, such as RCD, may be a faster method for selecting the highest quality seedlings in upland species, than assessing a combination of characteristics.

Bottomland Plantings

Seedling Survival

The scale of flooding on all bottomland sites was significant and impacted all plantations to varying degrees. Bottomland flooding is not an anomaly in this region (Stanturf and Gardiner, 2000) and presents the most challenging aspect to seedling survival in reforestation efforts (Williams et al., 1999). In this study, the WJ–S and WJ–N sites experienced relatively good survival rates (88 and 90%, respectively) while the two sites with significant flooding, LH–CL and MI, had lower survival rates (79 and 35%, respectively). The most apparent cause for the decrease in average survival among sites is the differing severities of stress induced by flooding. Survival decreased as flood depth increased from soil saturation with some ponding (WJ sites), to 7 feet of floodwater (LH–CL), and finally to 12 feet of floodwater on the MI site. Duration of flooding was not collected in a manner for analysis, but it is likely that the duration of flooding may be the overriding factor in seedling performance rather than flood depth. Therefore, when flood depth is addressed it is presumed that there was a concurrent, if not overriding, duration element involved. The survival at the LH–CL site, however, more closely resembles the WJ sites rather than the MI site. The MI site had almost twice the flood depth of the LH–CL site. Additionally, soils at the LH-CL site are silt loams and silty clay loams, which drain better than the clay soils at MI. A similar study (Williams et al., 1993) noted that some of the same species experienced greater survival, as the soil texture went from a clay to a silt loam even without flooding stresses. Clay soils, particularly smectite, shrink-swell, clays as found on MI, are problematic throughout wet periods, as they tenaciously hold water creating anaerobic conditions. These soils also can affect the survival in dry periods. If a drought occurs, the clay can crack open and allow excessive drying of the roots.

Cherrybark Oak

Cherrybark oak survival was 83, 86, 71, and 22 percent on the WJ –S, WJ –N, LH – CL, and MI sites, respectively (Table 22). There is a clear trend that reflects the sensitivity of cherrybark oak to flooding. The best logistic regression model for explaining cherrybark oak survival included depth of flooding and DTRF (Table 28). As flood depth increased and DTRF decreased, survival of cherrybark oak decreased.

Survival is related to the reduction or cessation of stomatal and photosynthetic activity in flooded seedlings (DeLaune et al., 1998; Gardiner and Krauss, 2001; Hosner and Boyce, 1962; Pezeshki and Chambers, 1985; Pezeshki and Anderson, 1997; Pezeshki et al., 1999; Williams et al., 1993). Mortality has also been associated with periods of increased vegetative growth prior to a flooding event due insufficient starch reserves during the period of interrupted translocation from sources to sinks, e.g., leaves to roots, (Angelov et al., 1996; Crawford, 1976). Results from this study indicate that these phenomena may have been partially alleviated by using seedlings with larger root systems. There was a positive relationship between FOLR and survival in the logistic regression model that did not include flood depth, thereby suggesting that an increased root system size can have a positive effect on survival in this species (Table 27).

The relatively good survival on the LH – CL site was surprising despite the severity of flooding. The difference between the survival of the LH – CL site and the MI site is likely attributable to the increased flood depth, and presumably duration, at the MI site as well as the difference in soils. Williams et al. (1993) found that cherrybark oak ranged from 90 percent on a silt loam to 50 percent on a clay, even without flooding stresses, which points out the importance of soil texture and associated DTRF (Williams et al., 1993). Family differences occurred on the WJ sites, but not the submerged sites (Table 23-26). Cherrybark oak survival was so tenuous on these flooded sites, particularly at MI, that any family differences were minimized.

Bur Oak

Bur oak survival on the MI site was relatively excellent (58%) in comparison with the other species, except Nuttall oak (Table 22). Unfortunately, bur oak was not planted on other sites, so no trends across sites can be observed. Bur oak survival was not explained by either logistic regression model nor were there family differences, which is probably related to the small sample size (Table 26). Tang and Kozlowski (1982) have observed morphological responses, e.g. hypertrophied lenticels and adventitious roots, in bur oak to extended soil saturation, which supports the higher survival rates on the severely flooded MI site.

Swamp Chestnut Oak

Swamp chestnut oak survival had excellent survival on the WJ sites (over 90%), but a lower survival rate (42%) at MI (Table 22). Swamp chestnut oak is clearly affected by either flood depth and/or soil type, and thus drainage. However, neither logistic regression model for survival in this species showed much relationship with depth of flooding (Table 27 and 28). The most significant relationship (negative) was with soil calcium. Flood depth is strongly correlated with soil calcium in this study, though the role or association of calcium and survival is not clear (Table 4).

This lack of explanation by flood depth and higher than expected ranking on the MI site were surprising, since swamp chestnut oak is described as weakly tolerant of flooding compared to other species (McKnight et al., 1981). The ranking on the MI site is also surprising because previous studies have shown a lack of resuming lost physiological functions in flooded swamp chestnut oak, as well as mortality being associated with periods of major vegetative growth (Angelov et al., 1996; McLeod et al., 1999). Swamp chestnut oak had one of the larger root systems of the planted species (Table 6), and the increased starch reserves may have allowed this species to better tolerate flooding (Crawford, 1976). Contrary to cherrybark oak, genetic differences in survival were expressed only on the MI site (Table 26) suggesting that natural selection of flood adapted families has occurred (Keeley, 1979; Nielsen and Jorgensen, 2003). It is premature, however, to differentiate between flood tolerant and non-flood tolerant genotypes based on data from one season (Houston, 1987; Kriebel et al., 1988; Thompson and Schultz, 1995), and a relatively low number of genetic families.

Water Oak

The survival of water oak was 85, 79, 68, and 22 percent on the WJ–S, WJ-N, LH-CL, and MI sites, respectively. The survival rates reflect the familiar trend of response to flooding that occurred in this study. The effect of flood depth is supported by the best logistic regression model for explaining water oak survival (Table 28). As flood depth increased, survival of water oak sharply decreased. This response is somewhat contradictory with previous research that groups water oak with willow oak in relation to flood tolerance (Baker and Broadfoot, 1979; Gardiner et al., 1993; McKnight et al., 1981; McLeod et al., 1999; Williams et al., 1993). The willow oak in this study consistently had greater survival across sites (Table 22).

Root collar diameter (RCD) and FOLR were also important to water oak survival (Table 27 and 28), thus indicating that water oak mortality may increase as starch reserves are depleted during flood events, as with conventional sized seedlings, e.g. seedlings <60 cm, (Crawford, 1976). Even though these seedlings were larger than conventional seedlings, the mean RCD and FOLR for water oak were some of the lowest for all species (Table 6). Non-flooded water oak was reported to have 64 percent survival across soil types (Williams et al., 1993). The large difference between the survival of the LH–CL site and the MI site (Table 22) is likely attributable to the increased flood depth and presumably duration. Similar to cherrybark oak, family differences occurred on all sites except the MI site where family differences were probably minimized by the severity of flooding (Table 23-26).

Nuttall Oak

The survival of Nuttall oak decreased as flood depth increased, but the decrease was comparatively small (91 to 66%), indicating that Nuttall oak was the most flood tolerant species planted (Table 22). These results are consistent with studies that have shown Nuttall oak to be relatively stable in relation to planting elevations and able to respond to flooding via physiological and morphological adaptations, e.g. hypertrophied lenticels and adventitious roots (McLeod et al., 2000; Pezeshki and Anderson, 1997). Nuttall oak survival has shown evidence of plasticity in regards to soil textures with survival greater than 90 percent in non-flooded, hydric soils (Williams et al., 1993). Root collar diameter, as opposed to flood depth, best explained Nuttall oak survival in this study (Table 27), thereby affirming the importance of sufficient carbohydrate reserves in the presence of flooding (Crawford, 1976). Similar to swamp chestnut oak, the magnitude of family differences increased as flood severity increased suggesting that flood adapted families do occur (Table 23-26) (Keeley, 1979; Nielsen and Jorgensen, 2003). Observations will need to be made, however, over a number of years to differentiate between flood tolerant and non-flood tolerant genotypes (Houston, 1987; Kriebel et al., 1988; Thompson and Schultz, 1995).

Willow Oak

Willow oak survival was similar to Nuttall oak on all sites, except at MI (Table 22). The extremely low survival (34%) on the MI site was unexpected, especially when compared to the good survival on the LH-CL site (87%). Willow oak has been classified as moderately tolerant, like Nuttall oak, but a reduction in survival based on planting elevation has been observed (McLeod et al., 2000). Both logistic regression models indicated that soil variables, strongly correlated to flood depth, were important, thereby indicating that there is at least a slight relation of willow oak survival and flood depth (Table 4, 27, and 28). The models also indicated that FOLR were important in survival, which again relates to carbohydrate reserves during flood events (Crawford, 1976).

Willow oak had some of the lowest amounts of FOLR for all species, which may have disposed it more to flood damage (Table 6). Similar to species with comparatively less flood tolerance, family differences did not occur as flooding increased, suggesting, in combination with survival rates, that the population samples used in this study were not well adapted to the flooding (Table 23-26).

Shumard Oak

Survival of Shumard oak was similar to water oak and ranged from 87 to 74 percent (Table 22). The combined logistic regression model showed that RCD was important to the survival of Shumard oak (Table 27), again indicating the importance of starch reserves to survival (Crawford, 1976). Family differences were observed only on the WJ-N site, possibly due to a small sample size (Table 24).

Seedling Height Growth

Seedling height growth is also an important component in successful bottomland reforestation (Williams et al., 1993). In this study, height growth decreased as flooding severity increased for all species. All species, on all sites, averaged negative height growth (-0.3 to –75 cm), with dieback occurring to varying degrees (Table 29). This dieback is not rare for the first year in outplanted seedlings, particularly on bottomlands (Williams et al., 1993).

All regression models indicated that dieback was more prevalent in taller seedlings (Table 34-36), probably caused by an increased demand for stored carbohydrates in the absence or partial absence of oxygen and internal physiological adjustments to regain a proper root/shoot ratio (Crawford, 1976). The taller seedling with the same FOLR and RCD as a shorter seedling will have greater dieback. Deer browse tended to decrease dieback in this study which may support the carbohydrate reserve concept. Deer browse occurred primarily before June on these sites and possibly before or during the initial flush. Assuming this occurred before or during flushing, the amount of carbohydrates in the roots would be greater than unbrowsed seedlings. Floodwaters could have covered the seedlings at this time, preserved carbohydrate reserves, and thus reduced dieback.

An interesting relationship between soil organic matter and dieback was observed. Multiple regression showed that as soil organic matter increased, dieback increased in water oak and willow oak, however, it decreased in bur oak (Table 34). Soil microorganisms consume oxygen as they respire and consume organic matter in the bulk soil, and particularly near roots (Marschner, 2002). The reduction of soil oxygen present in the rhizosphere of water oak and willow oak could be a contributor to dieback in these species. Water oak and willow oak growth characteristics may also predispose them to this association with increased dieback (Adams, 1982; Schlarbaum, 2003). The positive relationship between bur oak survival and soil organic matter is apparently different. Bur oak is a white oak species that may respond differently than the red oaks.

The trend of increasing dieback with increasing flood severity is common to all species and does not appear to follow the flood tolerance gradient as survival did, e.g. cherrybark oak had the least amount of dieback on the LH-CL site (Table 29). Significantly greater dieback in water oak and willow oak, particularly on the MI site, is due to a combination of factors (Table 29). Severe dieback is common to outplanted water oak (Adams, 1982). The most desirable seedlings of these same water oak and willow oak families were planted in an unrelated study where flooding was not present and severe dieback was also observed. The aforementioned lack of oxygen due to increased microorganism activity is possibly an exacerbating factor to this dieback pattern, but was not the primary cause.

Family differences occurred only in Nuttall oak on the flooded sites (Table 32 and 33). This indicates that natural selection of flood adapted families has occurred (Keeley, 1979; Nielsen and Jorgensen, 2003). More observations of flood events are needed before selection of flood tolerant genotypes can be made. (Houston, 1987; Kriebel et al., 1988; Thompson and Schultz, 1995).

Interactions between DTRF and first year height growth were observed on the WJ-S site and may be apparent on other sites and species as the seedlings age (Table 37). Water oak seems to prefer soils with redoximorphic features that are lower in the soil profile rather than near the surface which is consistent with other observations of sensitivity to flooding and soil saturation in this study. The other three species that showed interactions between DTRF and height growth indicate a more ambiguous relationship that may be elucidated as the seedlings age. Continued observations may allow species to differentiate in their response, both survival and height growth, to various ranges of DTRF. This could be a very useful tool in the planning stages of bottomland reforestation projects for species selection of certain planting locations.

Basal Sprouting

Basal sprouting is a response to stress in one form or another (Smith et al., 1997). Water oak showed a proclivity for sprouting in this study (1-31%) which is consistent with previous observations (Adams, 1982). Personal observation indicated that a general reduction in overall vigor and health in response to flooding was usually produced seedlings with basal sprouts.

There were differences in sprouting trends. Logistic regression showed that as flood depth increased, swamp chestnut oak sprouted more, while water oak and Nuttall oak sprouted less (Table 43). It appears that the negative relationship with flood depth occurred because of the less sprouting on the MI site for these species compared to LH-CL (Table 38). Swamp chestnut oak was not planted on the LH-CL site and therefore may not have been able to express this relationship. Species that were planted on both sites, with the exception of cherrybark oak, represented this same trend of reducing the occurrence of sprouting with an increasing severity of flooding. It is possible that increasing flood depth will increase the occurrence of sprouting to a certain extent and then the slope begins to decline beyond a certain flood depth or duration.

Greater initial height in Nuttall oak was associated with an increase in sprouting which is consistent with a comparatively greater reduction of vigor and health (Table 43). Root collar diameter (RCD) and FOLR were not related to sprouting even though it was thought that starch reserves would be pivotal in the seedling's ability to sprout. Sprouting, via dieback, influences the occurrence more than an ability, through starch reserves, to sprout. Family differences occurred in water oak and willow oak on the WJ-S site where they sprouted the most frequently of all species, and willow oak on the LH-CL site (Table 38). This, combined with family differences in height growth, suggests that the dieback/sprouting phenomena in water oak is not present in all families and thus early height growth may be able to be selected for after sufficient time for family differentiation to become clear (Houston, 1987; Kriebel et al., 1988; Thompson and Schultz, 1995).

Upland Plantings

Seedling Survival

Survival on upland sites was generally excellent (90–100%) and differed only slightly among species (Table 58). There was a trend in which seedlings (excluding pin oak) had better survival on the AC site. Although both plantings were on upland sites, AC appears to have a higher water table than LH-UP. During the AC planting, some holes filled with water and DTRF was between 2 and 30 cm., as compared to >50 cm at LH-UP. The increased soil moisture could have correspondingly increased survival at the AC site.

Logistic regression showed that initial height, RCD and buffer pH of the soil were important to black walnut survival (Table 62). Height and RCD were related to survival, indicating that planting larger seedlings increases the probability of survival. The negative relationship with buffer pH shows that black walnut survive better on heavier soils which are often have a higher soil moisture. This concurs with known site requirements for black walnut (Hardin et al., 2001).

Initial seedling measurements and soil parameters influenced a small portion of survival for the oak species, except northern red oak (Table 62). Greater FOLR and height growth increased survival in southern red oak (FOLR) and pin oak (height), which is consistent with previous studies that have shown greater FOLR to increase survival (Thompson and Schultz, 1995). Potassium was also important to southern red oak and could be related by the fact that lower potassium levels in the seedling can inhibit uptake of water (Marschner, 2002). Survival of black oak decreased with increasing sodium levels in the soil, which can reduce available moisture to roots systems (Marschner, 2002). No variables were significant in explaining northern red oak survival on PE, but other studies have shown that FOLR has a positive influence (Thompson and Schultz, 1995). Further observations will tell whether FOLR is important to survival over time.

Height Growth

Height growth differences among species occurred only on the AC site, where black walnut had a substantial amount of dieback (Table 63). The northern red oak on PE experienced dieback, possibly because of the late planting date and deteriorating condition of the seedlings, e.g. somewhat drier roots. Only two species, black oak (LH-UP) and northern red oak (PE) had family differences, and the differences were more notable in northern red oak. Several more years of observation will be needed to determine if selection for desirable traits will be effective (Houston, 1987; Kriebel et al., 1988; Thompson and Schultz, 1995).

The multiple regression showed that greater initial height was inversely related to first-year height growth in all oak species (Table 67), which concurs with Thompson and Shultz (1995). This is presumably because taller stems require more carbohydrates to maintain the stem and larger root systems are indicative of greater carbohydrate reserves. Conversely, increased RCD and FOLR promoted height growth in pin oak, northern red oak, and black oak, which is consistent with Kormanik (2002). The importance of RCD and FOLR to height growth is likely due to increased carbohydrate reserves in the roots that are able to support greater height growth. Soil boron and CEC also were important to height growth of several oak species. Boron was positively related to growth in pin oak because it is important in the development of new cells in the meristematic tissue (Marschner, 2002). The reason that boron is important only to pin oak is unknown, as well as the negative role of CEC with black oak.

Deer Browse

Deer browse was negligible on all but three of the seven sites (8-27%). Only trees under 170 cm in initial height were browsed. No evidence of terminal bud damage from browsing occurred in seedlings that had an initial height of 170 cm or greater. This height is greater than what Oswalt (2003) noted in a northern red oak study in the same region (148 cm). No preferences for browse among oak species were noted, but black walnut was almost never browsed (Figure 8).

A visual assessment of deer browse maps revealed that browse was concentrated toward the edges of the sites that were near the forest edge, although browse did extend into the interior of the sites. Logistic regression revealed that basic seedling and soil characteristics that promote growth seemed to be associated with an increase in deer browse, thus indicating that deer preferably select healthy and vigorously growing seedlings (Table 68). Buckley (2002) found that larger seedlings were preferentially browsed also, which concurs with results from this study. There was no particular attempt or methods undertaken to determine if soybeans planted near the seedlings increased or decreased deer browse. However, it is worthy to note that AC, where soybeans were not grown, had the lowest deer browse occurrence.

Groundcovers and Competition

The planted groundcover was very effective on WJ-S site where browntop millet maintained dominance throughout the growing season. Many hours of labor were needed to produce a successful groundcover on the WJ-S site. The LH-UP site had an excellent groundcover of winter wheat for the first several months of the growing season until it began to naturally decline. Groundcovers failed when less than ideal planting methods were used or when the groundcovers were planted prior to substantial flood events. Groundcover planting after seedling establishment was difficult and time consuming. A perennial grass, e.g. redtop grass (*Agrostis gigantean* L.), may be a better option as a groundcover to avoid the need for annual reseeding in the tree rows and more effective resistance to volunteer vegetation (Dey et al., 2003). Perennial species could also be planted the fall prior to seedling establishment.

Groundcover failures were quickly colonized by volunteer vegetation that covered nearly 100 percent of the soil for most sites. While this may be a planted groundcover failure, the benefits to wildlife may exceed the benefits that the planted groundcover could offer through increased diversity. Volunteer vegetation that overtopped seedlings appeared to only protect them from deer browse and provide a less exposed growing environment that lends itself to the moderate shade tolerance of oaks. Overtopped seedlings appear to be capable of attaining a dominant position in the near future.

Crop Production and Economics

A 40 percent reduction in cropland due to alley cropping was significant to farmers, but this amount could be reduced through different alley cropping designs. Three tree rows were planted next to each other, instead of single rows, in order to shorten the length of time needed for reforestation. In addition to the reduction in cropland, a yield loss of 10 bushels per acre was reported, but only at the WJ-S site. The reduction in soybean yields is not due to competition with seedlings during the first year of growth, but could be related to the groundcover treatments. Ditches were not created on this site, as in previous years, due to the alley cropping design, and may have caused some water logging during the growing season, thereby reducing soybean yields.

Auger planting 160 high-quality seedlings per acre (total acreage) along with proper groundcover establishment averaged a one-time cost of $212 per acre (total acreage); significantly greater than planting conventional-sized seedlings with a dibble bar.

Crop production, based on five year prices of soybeans, yielded a profit of $55.25 per acre (total acreage). The net loss of $51.65 per acre lost to alley cropping, is considerable, but significantly less than if the entire field was planted in trees and no crops were produced. Crop production in subsequent years will not have the initial costs of alley cropping to detract from the overall profit. The sunflower/millet crop on the AC site was not harvested for production, and soybeans were planted the previous year so the effect of alley cropping cannot be quantified for this site.

CHAPTER VI.

CONCLUSIONS

First-year results suggest that reforestation efforts through alley cropping possess great potential. Bottomland sites required particular attention in the planning process for proper species placement within the site. This proved to be worthwhile, as the depth and therefore duration of flooding was important to the survival and subsequent growth of certain species more than others.

High-quality seedlings likely played a crucial role in the survival and growth of seedlings across all studies due their larger size. Greater root collar diameter and first order lateral roots allowed flooded seedlings to improve survival and reduce dieback, while producing greater height growth on the upland seedlings. Although it is too early to state concretely, there appeared to be genetic families that were more adapted to flooding as well as having increased survival and height growth across studies.

Alley cropping helped offset the high initial cost of planting quality-improved seedlings through income from soybean production. The use of groundcovers to retard volunteer vegetation was effective when properly established. In the absence of successful groundcovers, volunteer vegetation quickly colonized the tree rows and produced a native groundcover that produced nearly 100 percent cover along with many wildlife benefits. Crop rows also were effective in eliminating or reducing the establishment and lateral spread of volunteer vegetation.

Based upon this study, the following are recommendations for establishing multiple-row alley cropping plantations, particularly on bottomlands.

1. Gather detailed hydrologic data on the site, e.g. depth of flooding, duration, and delineate locations for appropriate species;
2. Decide on a crop row width that will prevent overlapping of farm equipment;
3. Utilize only the highest quality seedlings with greater than average root collar diameter and first order lateral roots;

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APPENDIX

APPENDIX

Figure 9 – Strawberry Plains Audubon Center Site.

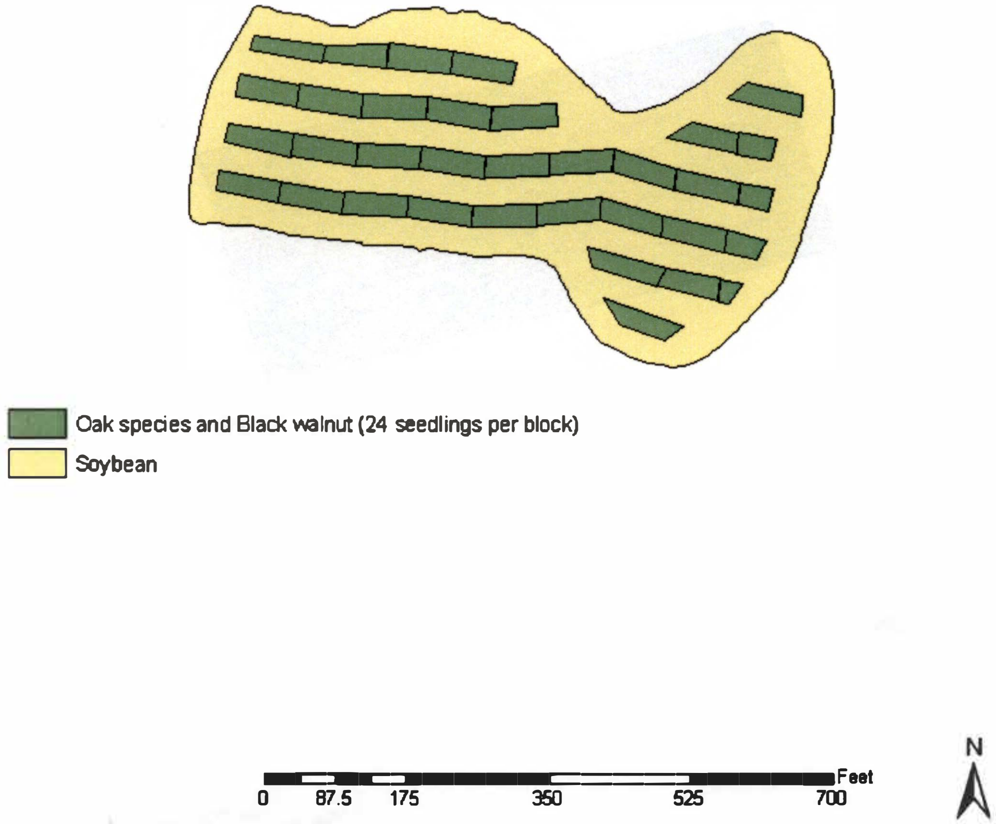

Figure 10 – FWS Lower Hatchie NWR Upland Site.

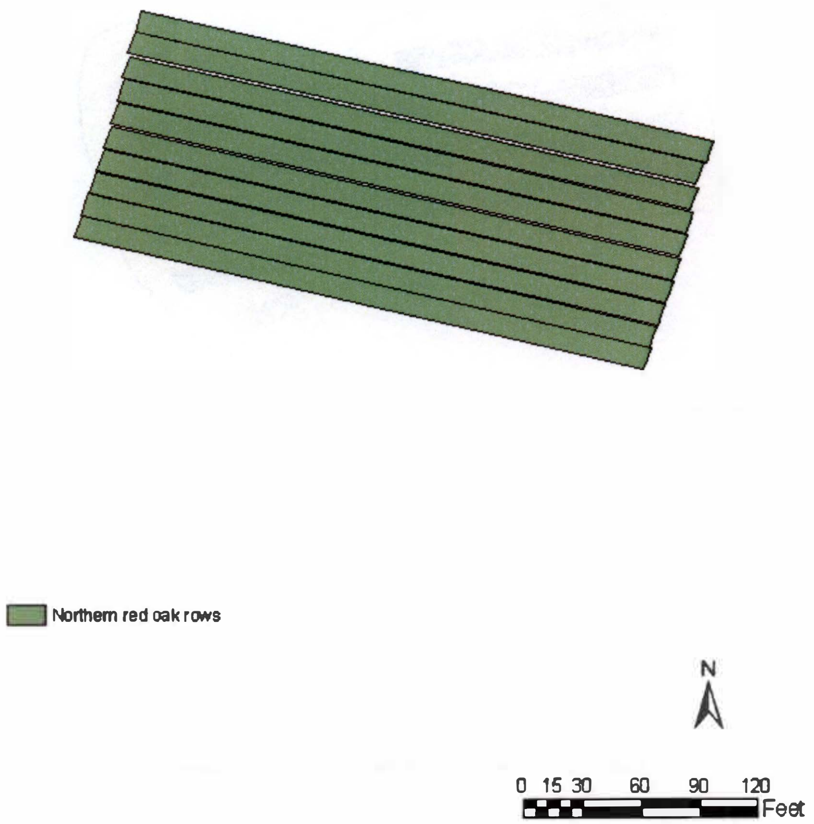

Figure 11 – Pat Estes Tree Farm Site.

VITA

David Michael Casey was born on October 15, 1976 in Nashville, Tennessee to Edward L. and M. Ann Casey. He graduated from David Lipscomb High School in Nashville, Tennessee in May of 1995. In the fall of that same year, he began his undergraduate career. After several schools and working as a lawn care professional, he graduated with a Bachelor of Science degree in Environmental Agriscience from Tennessee Technological University in May 2001. In the summer of 2001, he started work for the Tennessee Department of Environment and Conservation as an environmental specialist in Nashville, Tennessee. In August of 2002, David entered The University of Tennessee at Knoxville Graduate Program and began to work towards a Master of Science degree in Forestry under the direction of Scott E. Schlarbaum in the Tree Improvement Program. In July 2004, David accepted a Forester Trainee position with the United States Forest Service on the Grandfather Ranger District of the Pisgah National Forest in North Carolina.